Frequency dependence of effective bottom attenuation due to environmental variability

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Work supported by ONR, Code 321OA

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 DEC 2002	**N/A**	**-**

4. TITLE AND SUBTITLE	
Frequency Dependence of Effective Bottom Attenuation Due to Environmental Variability	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Physics, Naval Postgraduate School, Monterey, CA 93943 and Advanced Sonar Technology, Naval Undersea Warfare Center, Newport, RI 02841**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
Also see: M001452, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**39**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Introduction

- Traditionally, ocean sediment attenuation assumes linear frequency dependence such that loss per distance has the form $a = bf$ (or constant loss per wavelength), where α may have units 1/m or dB/m, and b=constant. Parameterization of sediment attenuation then relies on determination of b.

- More recent inversion studies (e.g., Zhou et al., 1987) have suggested non-linear frequency dependence of attenuation, i.e., $b = cf^{x}$ such that $a = cf^{(1+x)}$. Zhou et al. found *x* ~ 0.7, so $a \propto f^{1.7}$

- Physical models of sediment attenuation mechanism unclear on inherent nonlinear response versus effective nonlinear response due to variable environmental influences.

Model

- Monterey-Miami Parabolic Equation (MMPE) model used to compute propagation. Inputs may include range-dependent sound speed profiles, water-sediment and sediment-basement interfaces, sediment/basement sound speed gradients, sediment/basement sound speed and density fluctuations, and constant sediment/basement attenuation values (linear frequency dependence assumed).

- Sound speed profiles input deterministically.

- Interface roughness based on realizations of spectral model,

$$W_h(K) \propto \left(1 + L_h^2 K^2\right)^{-b}$$

- Sound speed/density variability based on realizations of spectral model

$$W_{dc}(K, M) \propto \left(\Lambda^2 K^2 + M^2\right)^{-g}$$

Approach – Part I

- Direct numerical evaluation of environmental fluctuations influence on effective frequency dependence as measured by simple, linear correlation analysis.

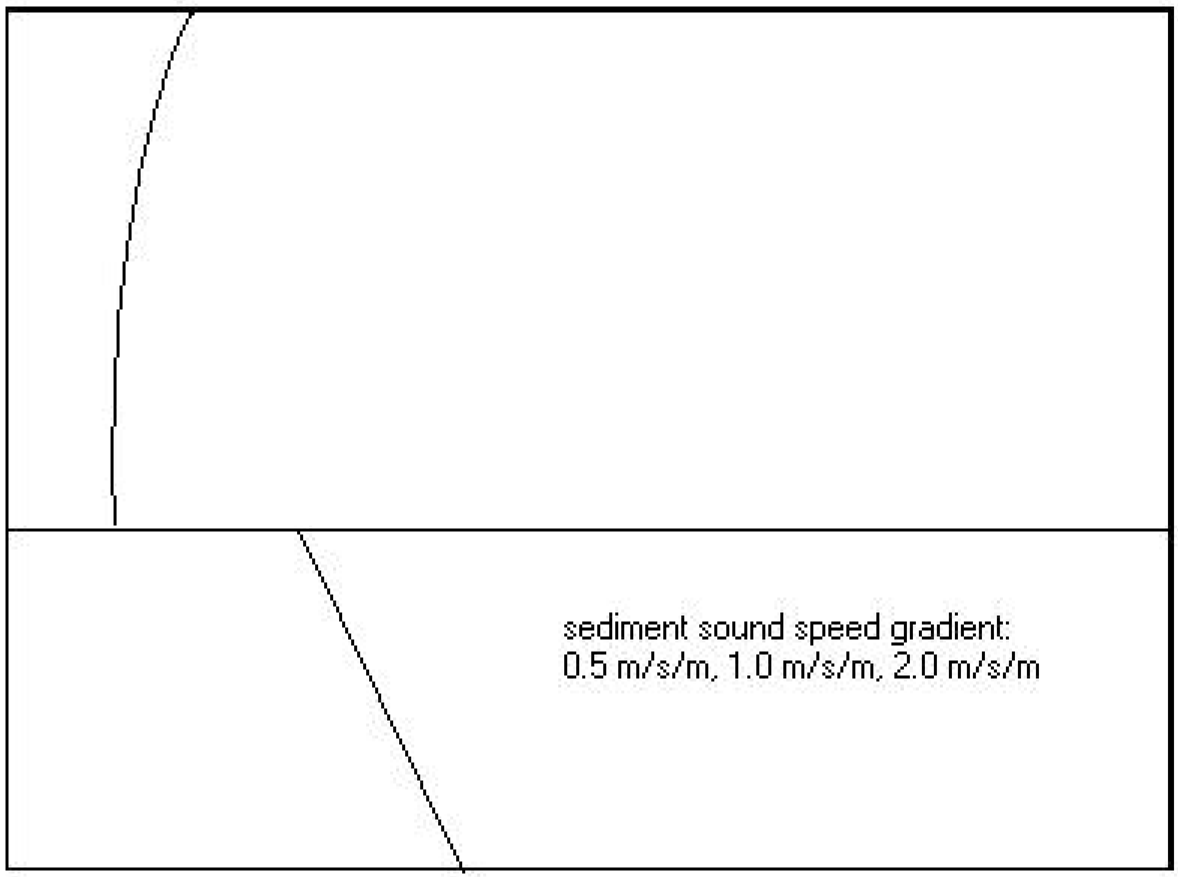
- MMPE model run assuming b_{sed} = 0.15 dB/km/Hz for numerous environments containing perturbations. Results in complex pressure values at multiple depths: $p(r, z_j)$ with r = 10 km, and z_j containing 16 depths from 0 to 100 m.

- MMPE model then run for range-independent environment (avg SSP, no sediment gradient, all other values constant). Sediment attenuation then varies from b_{sed} = 0.025 to 0.5 dB/km/Hz. Results in complex pressure replica matrix $p_b'(r, z_j)$.

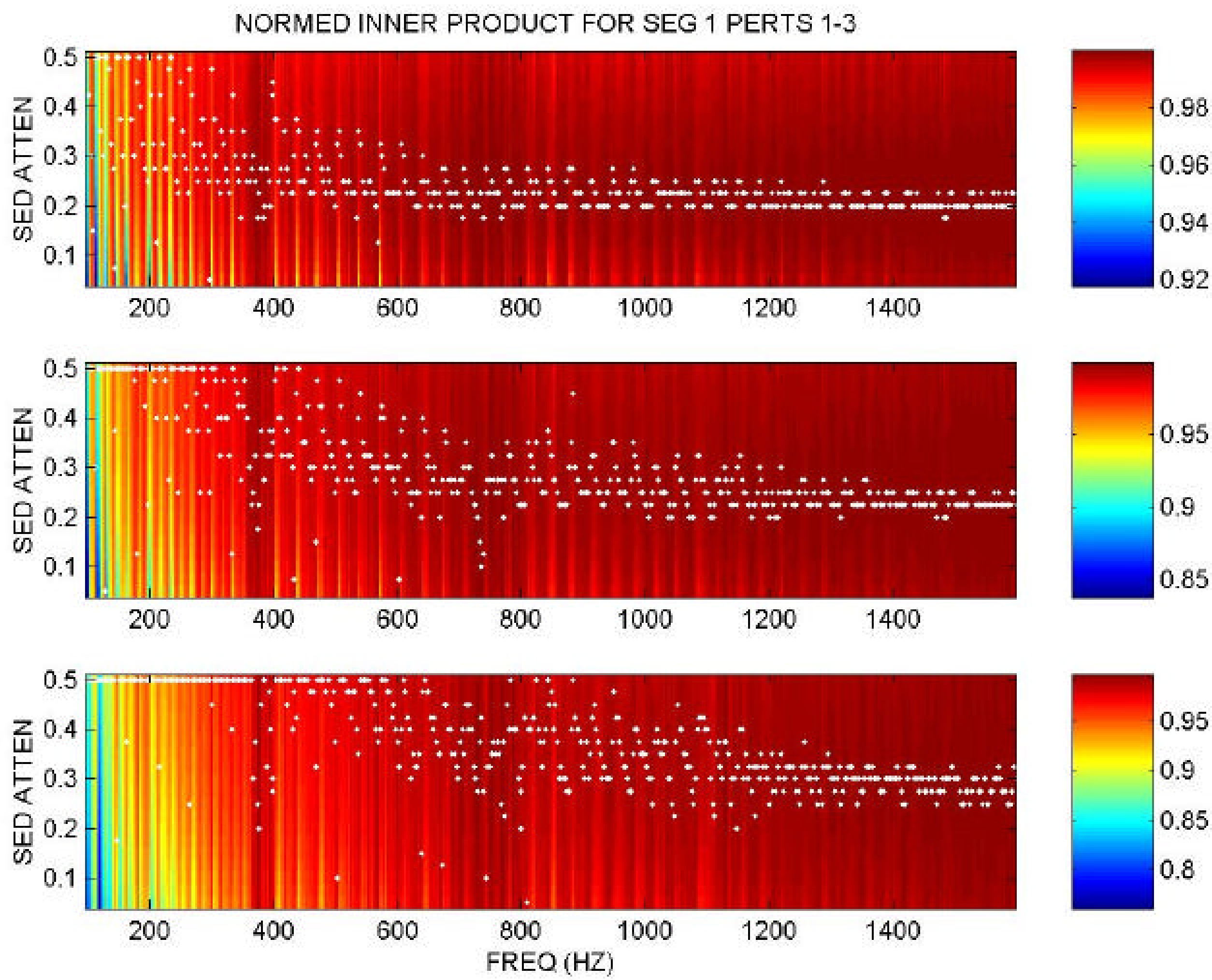
- Effective attenuation determined by maximizing normalized correlation between pressure magnitudes over band of frequencies,

$$C(r,f,b) = \frac{\sum_j \left|p(r,z_j)\right| \left|p_b'(r,z_j)\right|}{\sqrt{\sum_j \left|p(r,z_j)\right|^2 \sum_j \left|p_b'(r,z_j)\right|^2}}$$

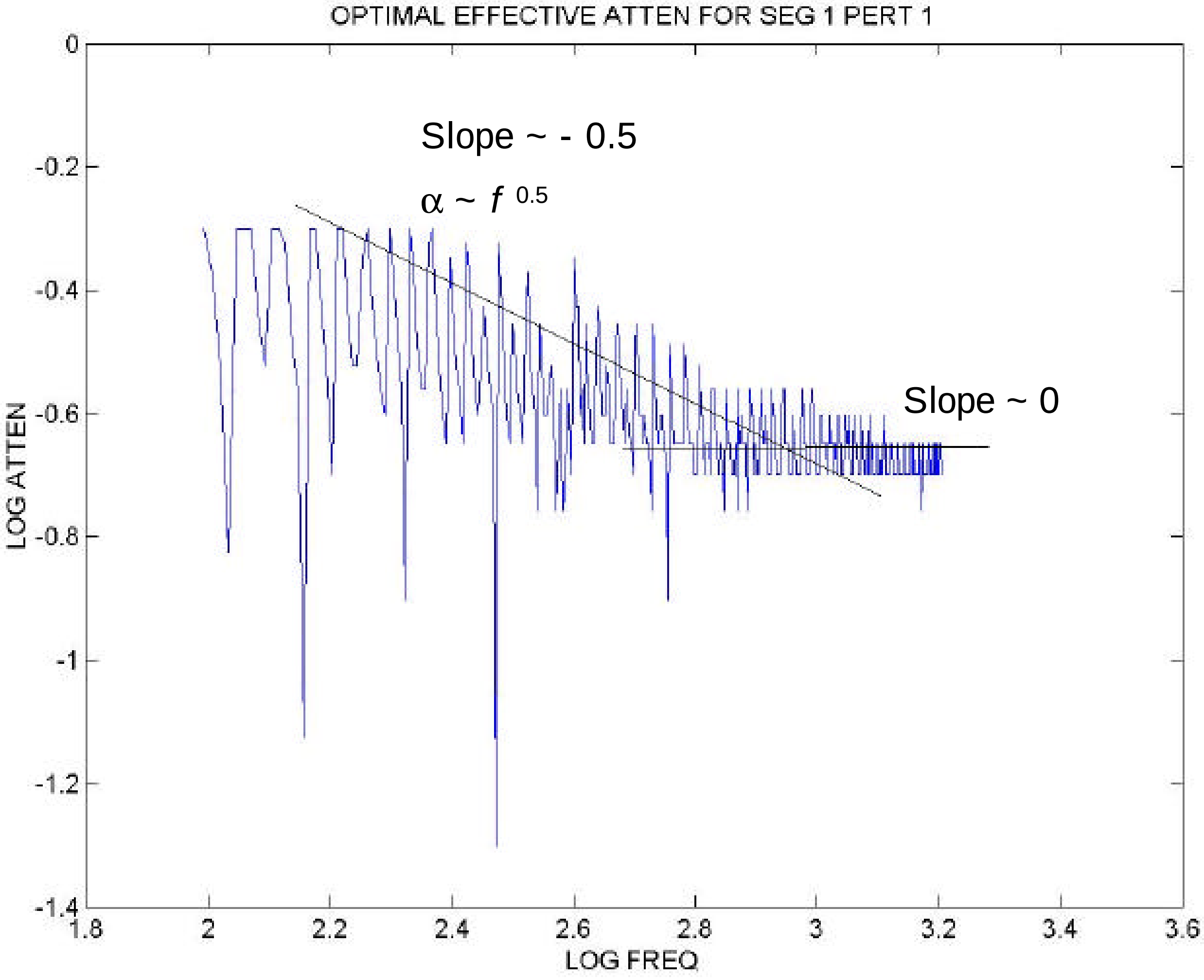
Environment 1



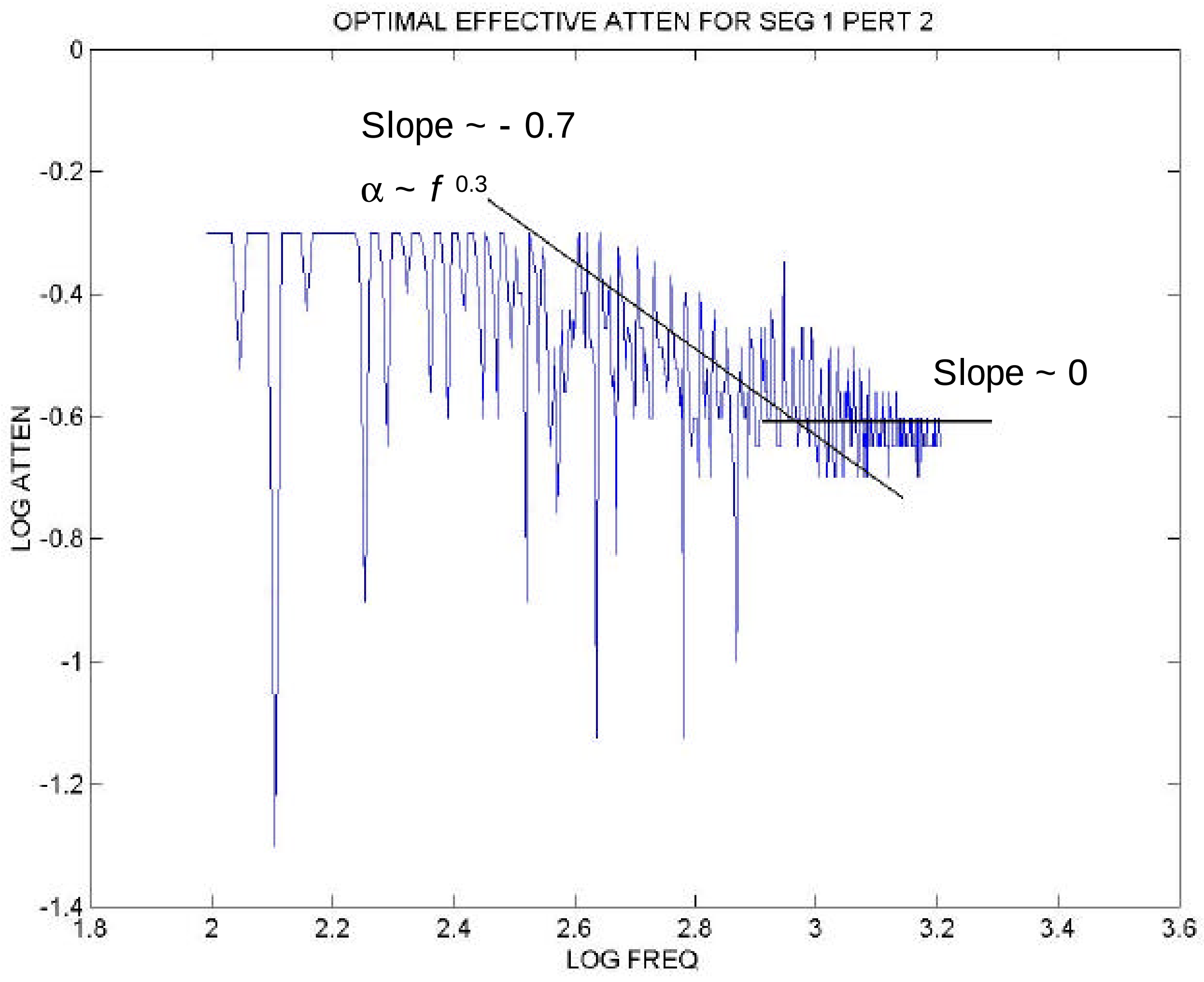
Results, Environment 1



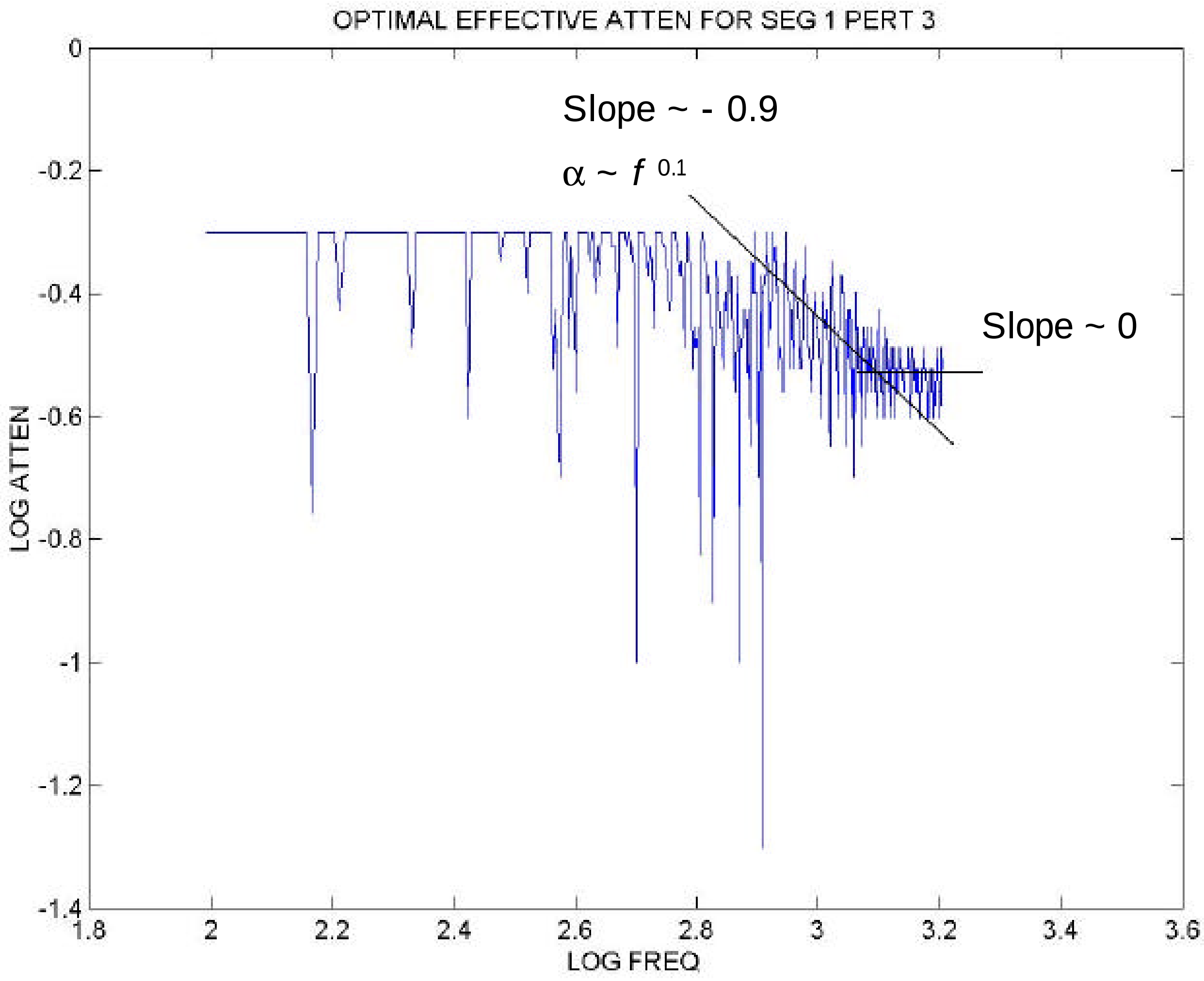
Log-log analysis of Env 1, Pert 1



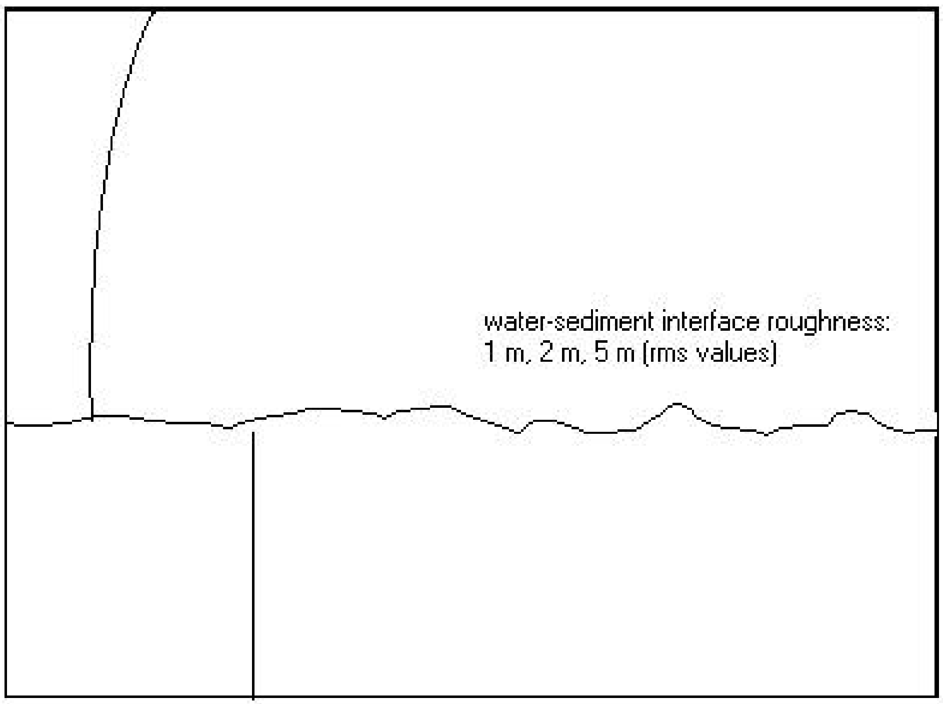
Log-log analysis of Env 1, Pert 2



Log-log analysis of Env 1, Pert 3



Environment 2



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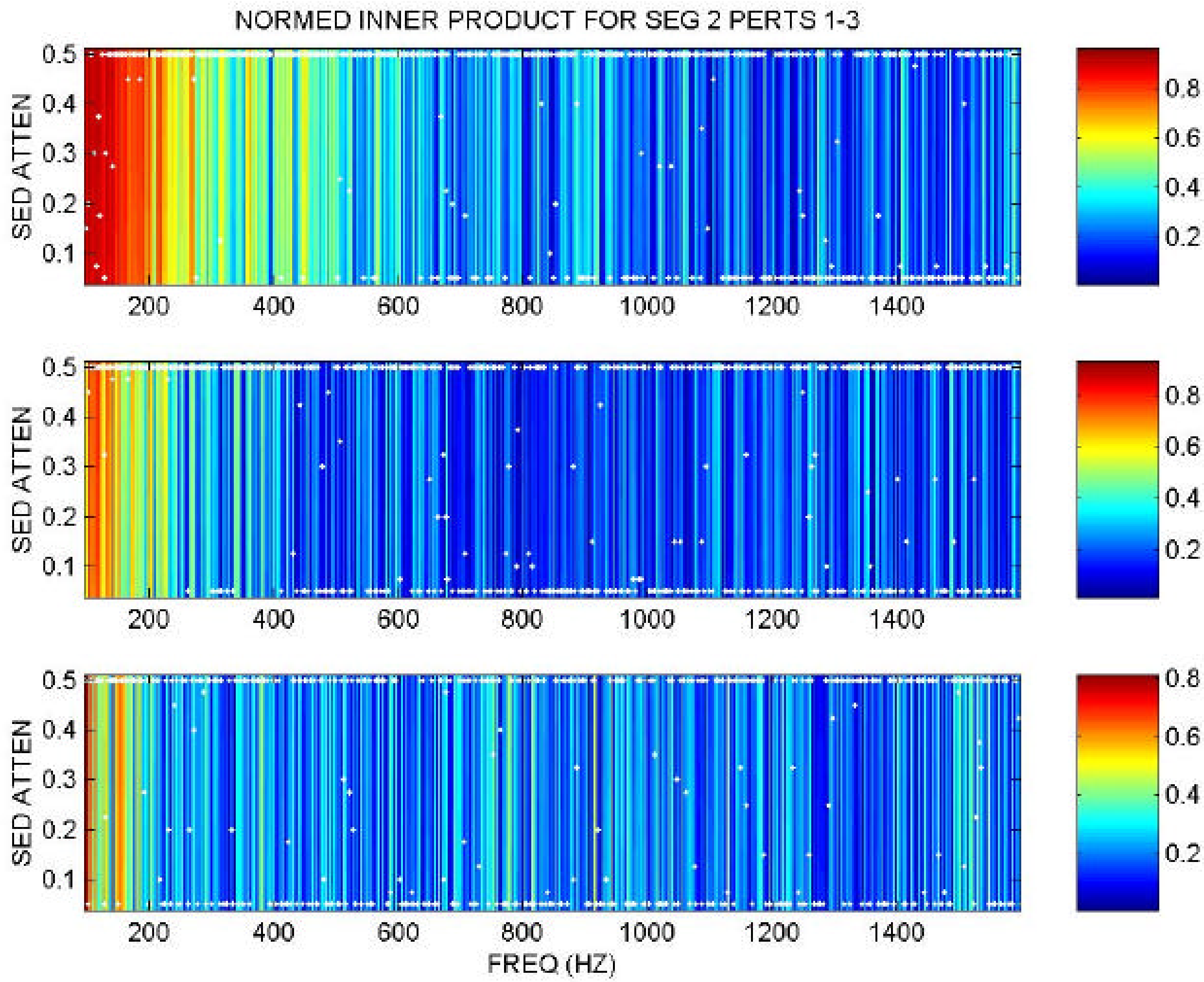

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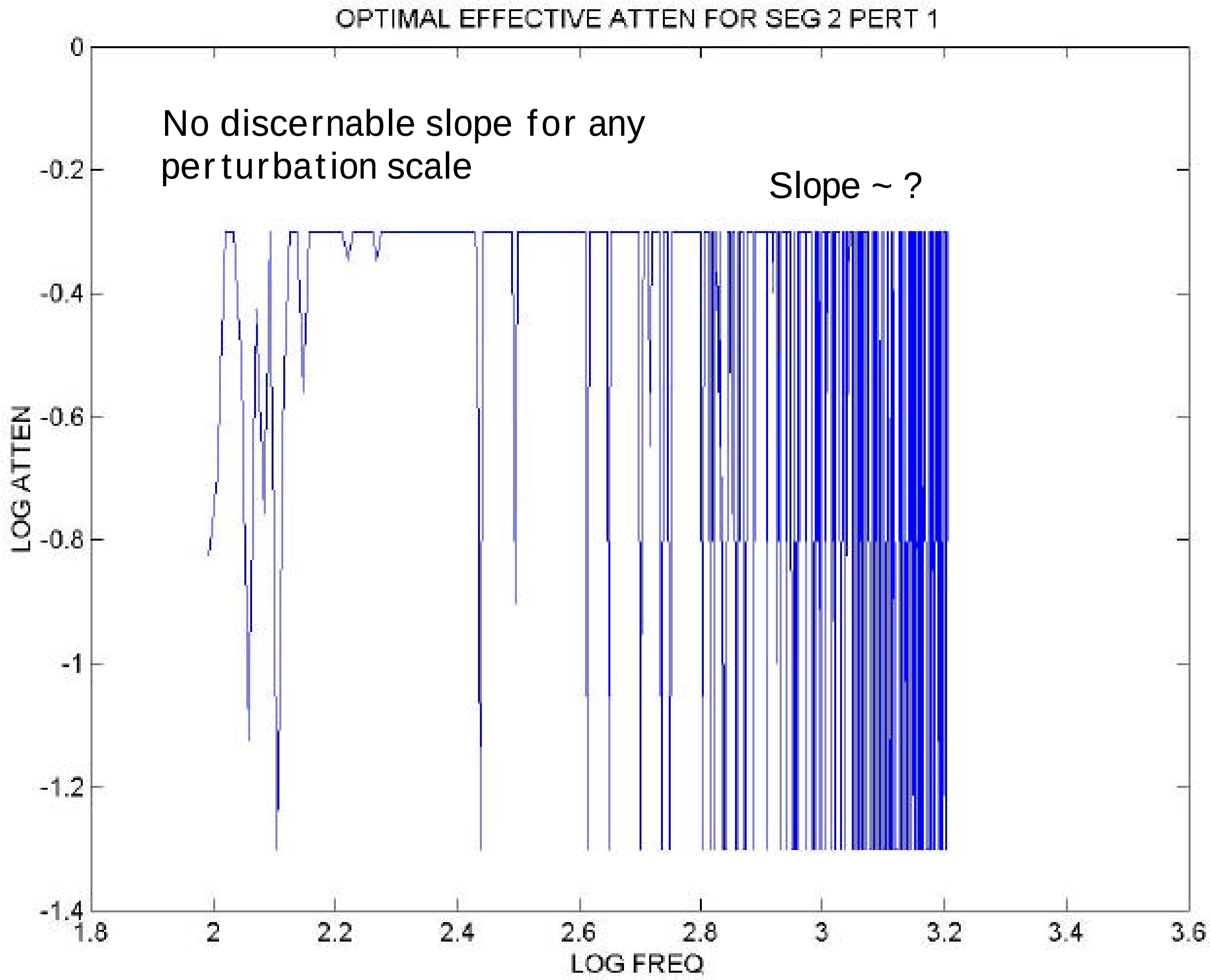
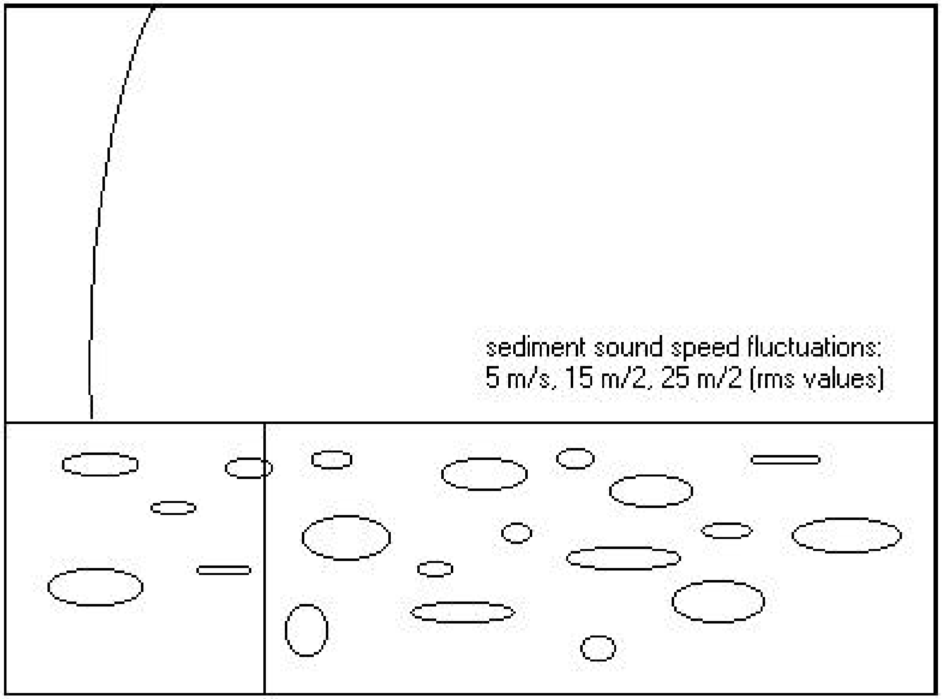


Environment 3



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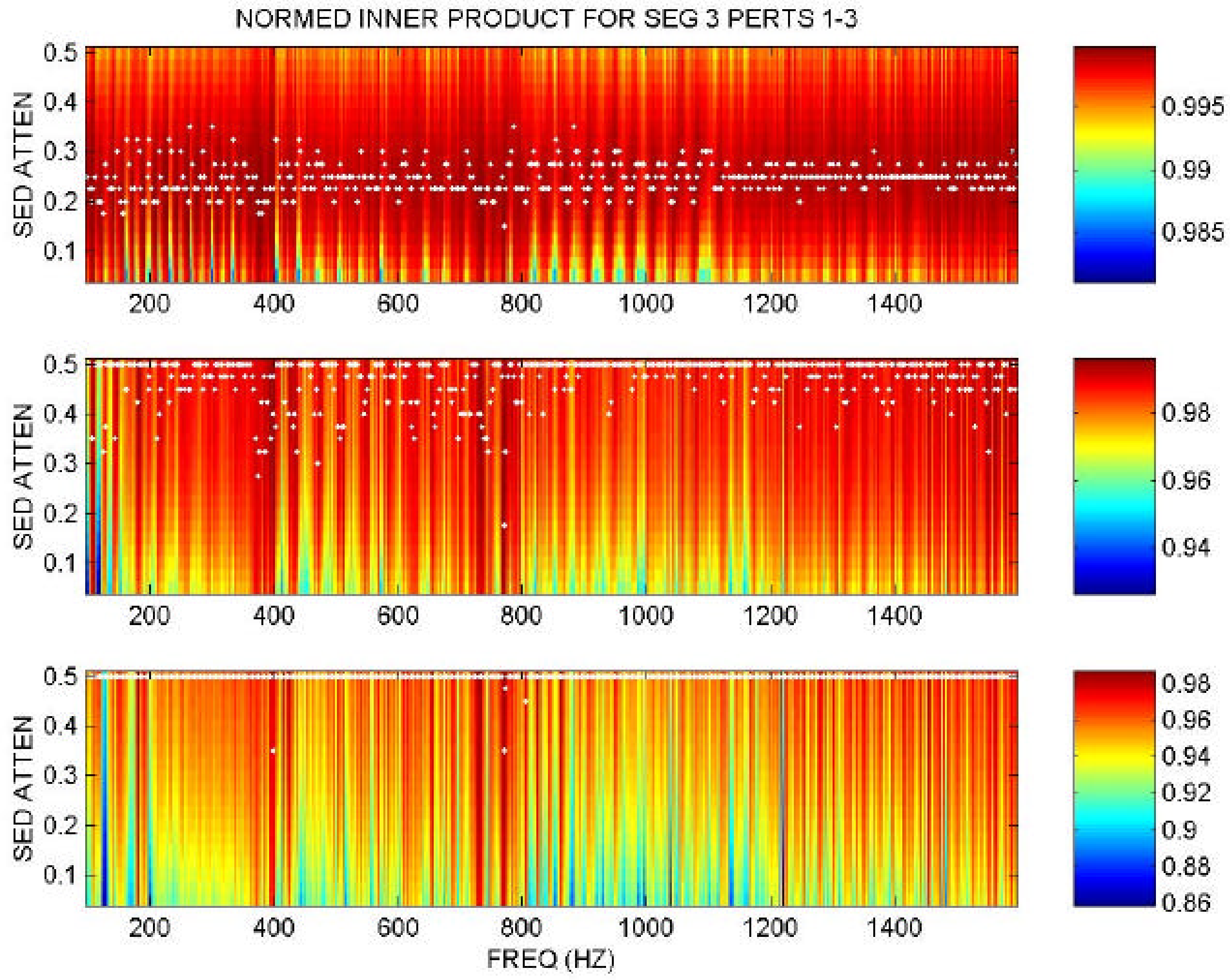

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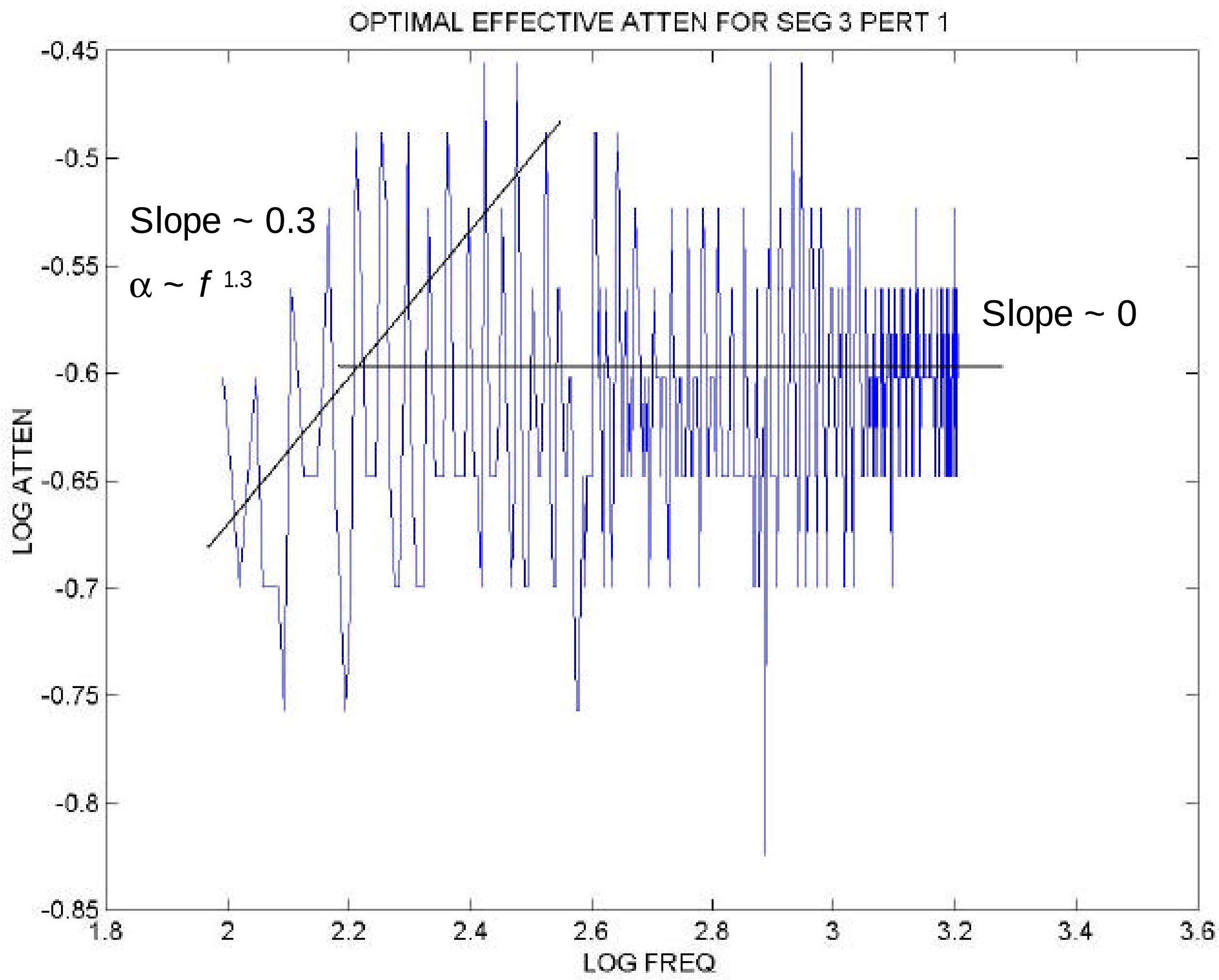

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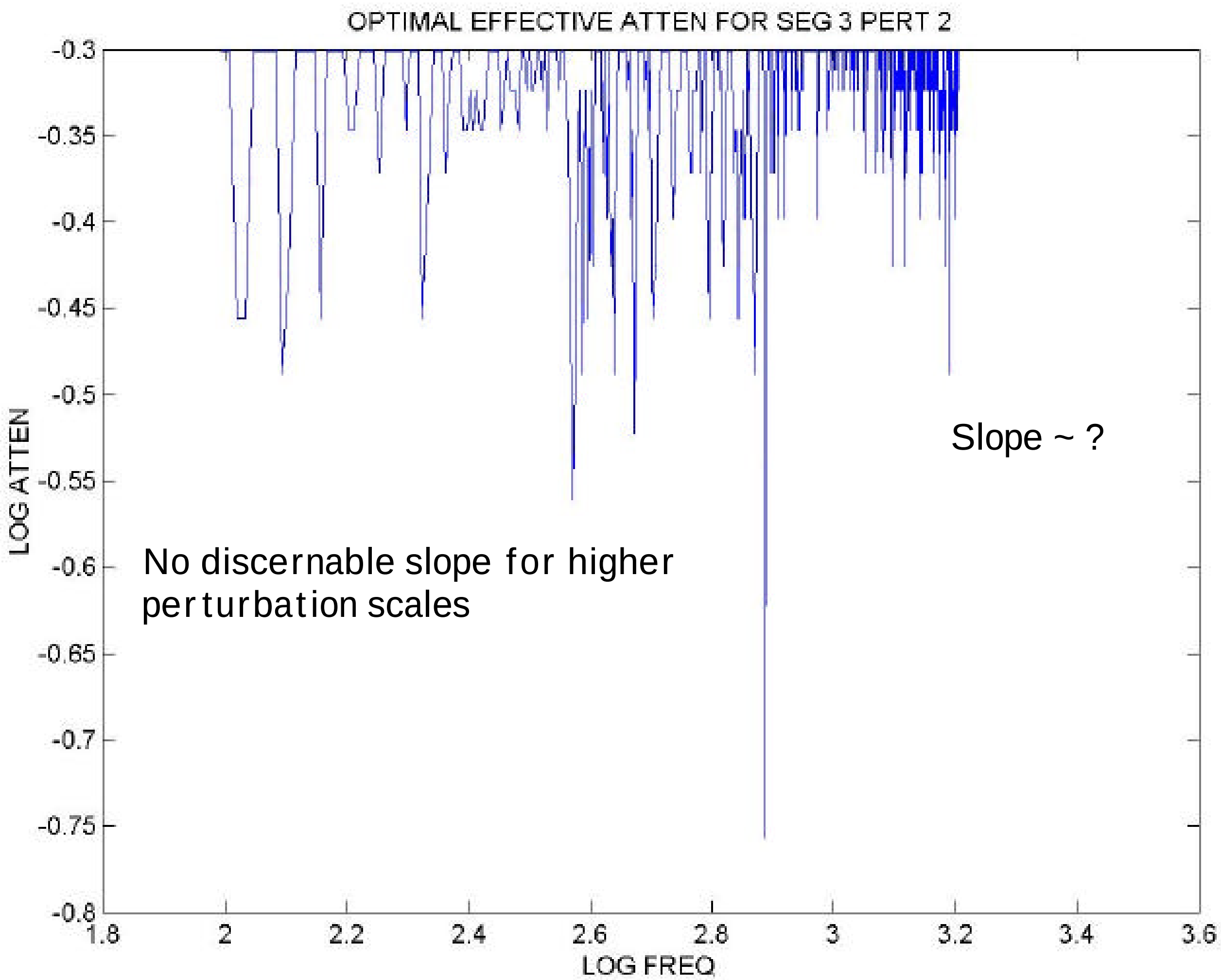
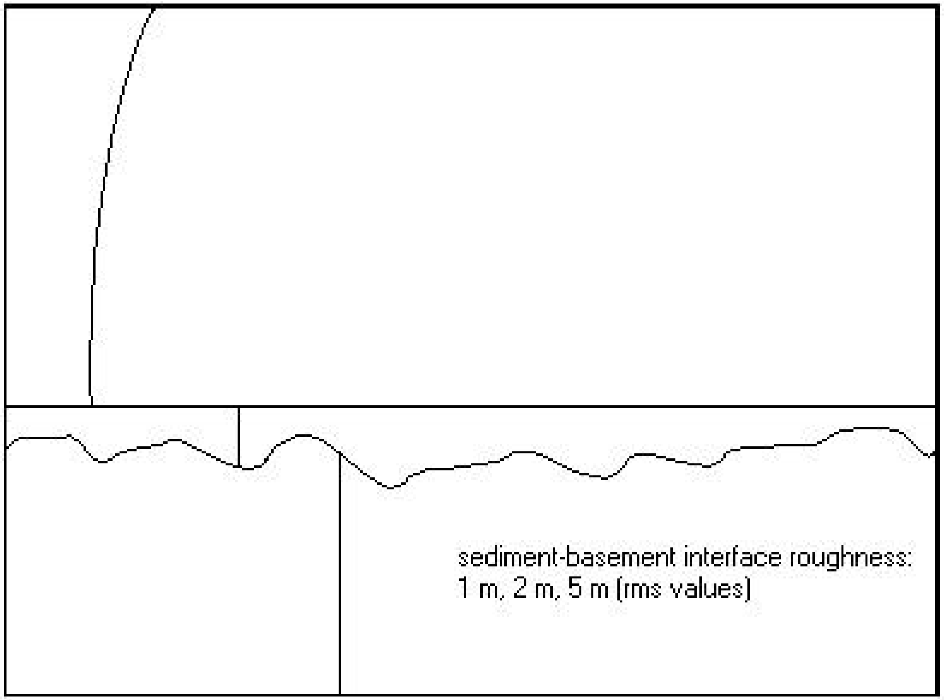
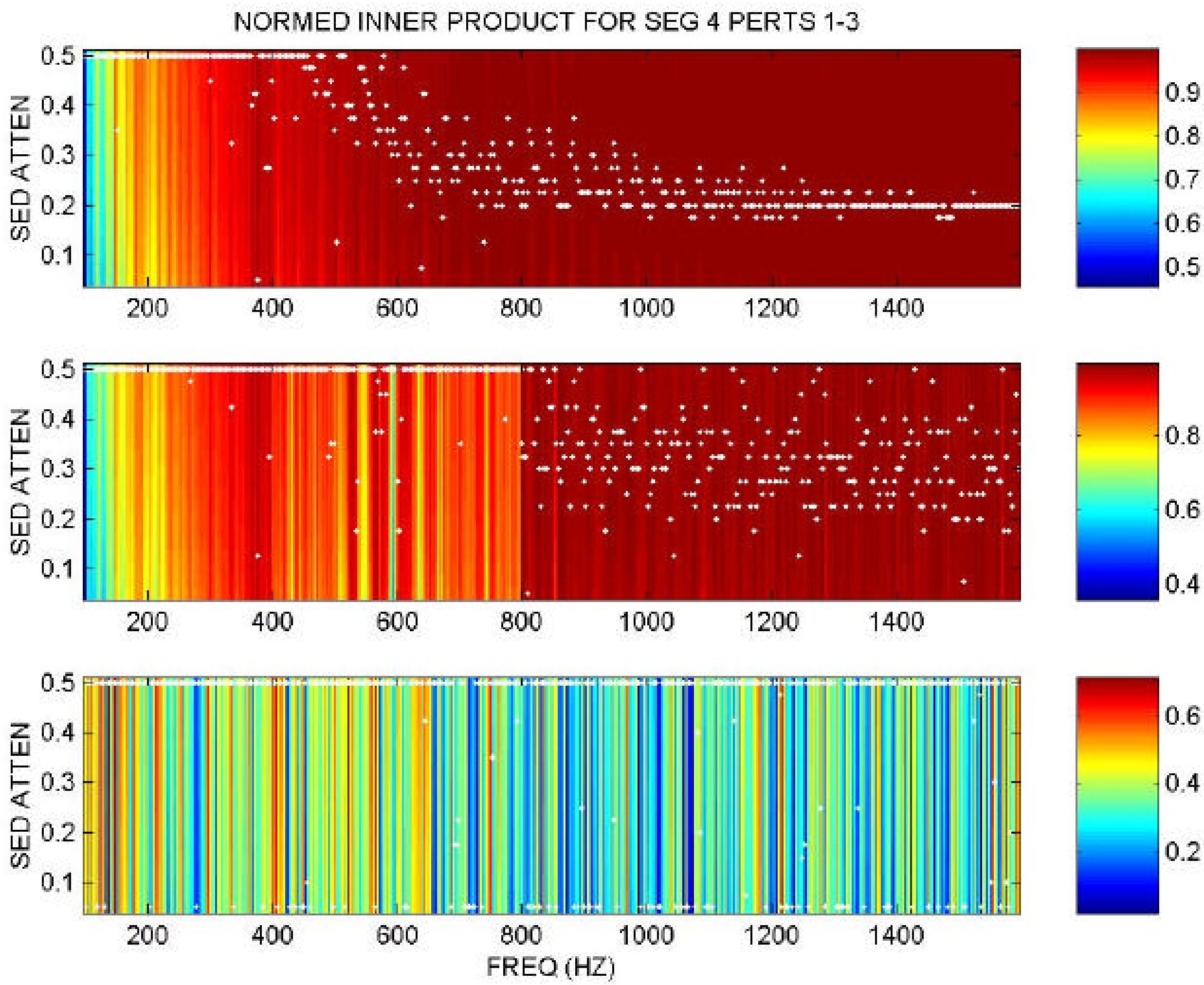


Environment 4



Results, Environment 4



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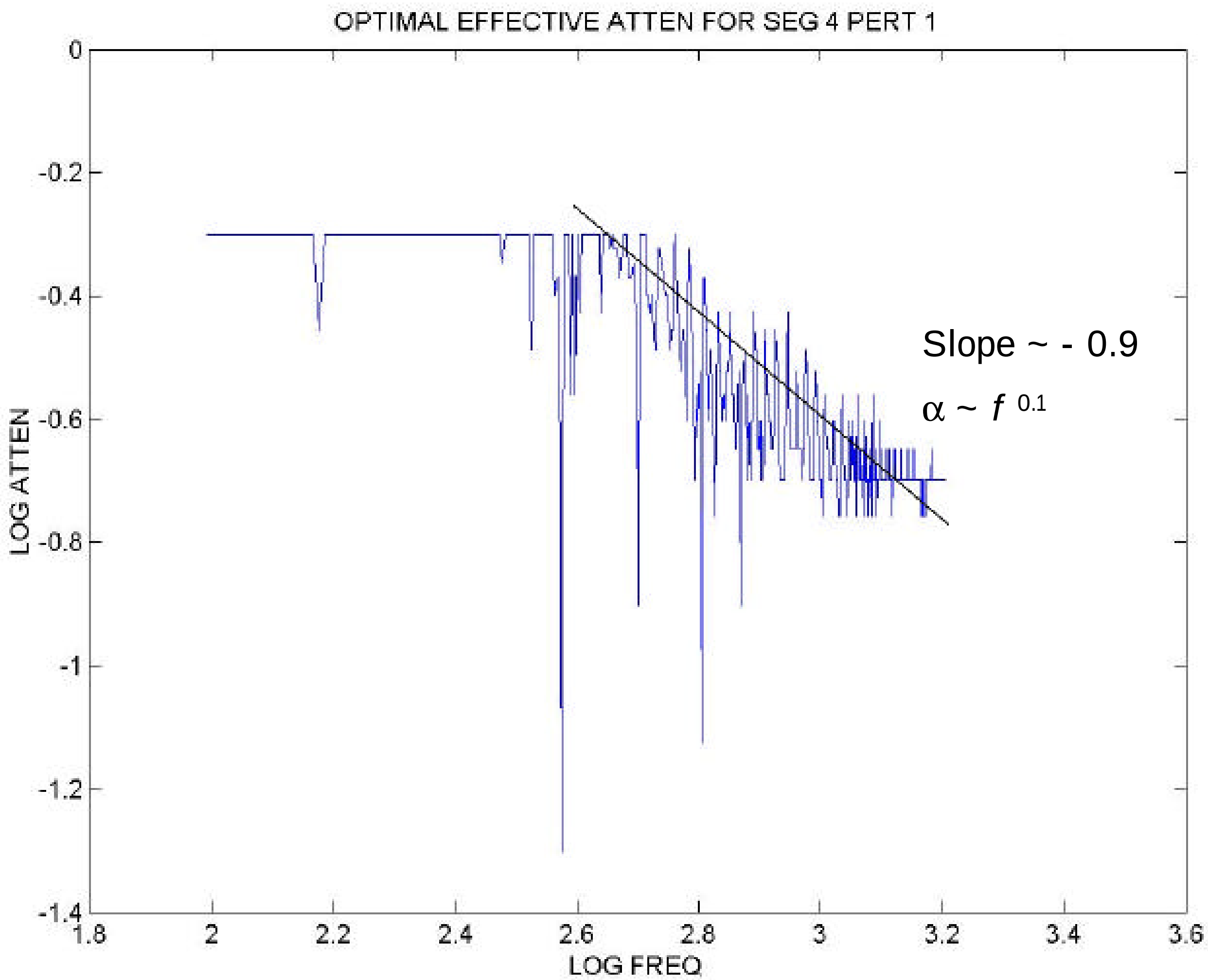

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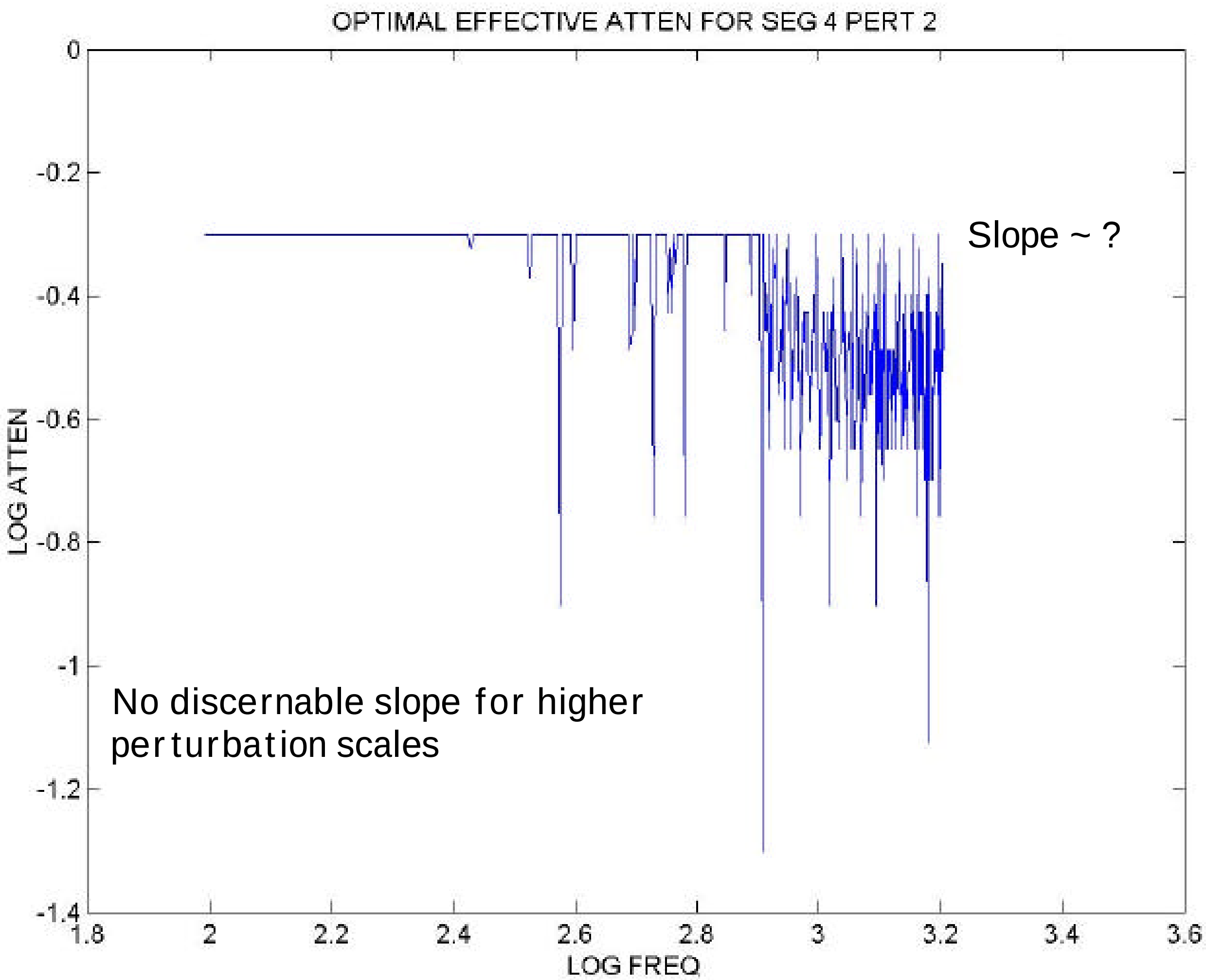
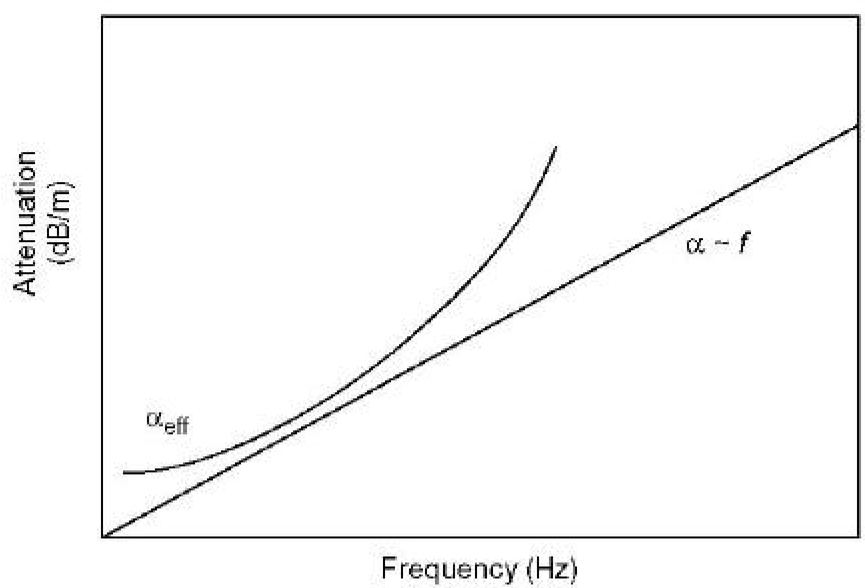


Summary – Part I

- Environmental fluctuations <u>can</u> have significant impact on inversion of sediment attenuation.
- Water-sediment interface roughness seemed to create largest variability in effective attenuation. No trend observed over bandwidth.
- Sediment sound speed gradients and sediment-basement roughness both seemed to introduce noticeable trend in frequency dependence at larger ranges. Specifically, there was enhanced attenuation at the lower frequencies with values of *x* typically –0.5 to –0.9 (i.e., $\alpha \sim f^{0.1}$ to $\alpha \sim f^{0.5}$) over the band f = 100 – 500 Hz.
- These results imply higher loss per wavelength at lower frequencies, or even nearly constant loss per distance over band.

Summary – Part I

- Cause may be primary loss mechanism in these cases due to sub-sediment/basement effects. Thus, lower frequencies interact more readily, thereby increasing the effective attenuation.
- This suggests environments with x > 1 may be due to water/sediment interface, or near interface, influences. Potential causes could be small-scale roughness/scattering or even near bottom biologics. Longer range effects could even be related to rough surface scattering.
- If higher frequencies incur enhanced scattering, may expect frequency dependence of attenuation of the form



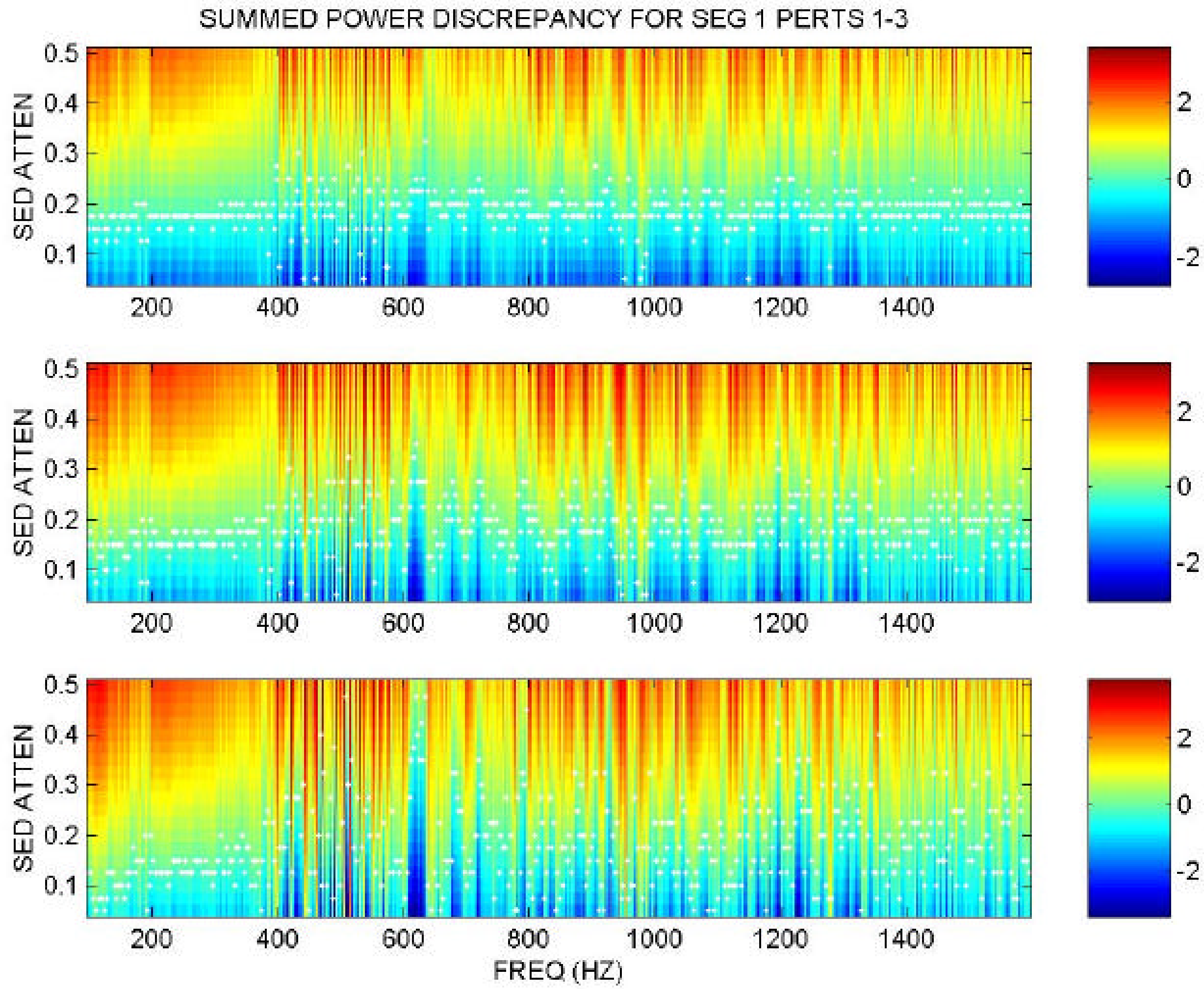
Approach – Part II, New Cost Function

- Previous cost function based on incoherent correlation over depth. However, no reason to expect correlation between scattered field structure (e.g., from rough interface) and range-independent field with effective attenuation.

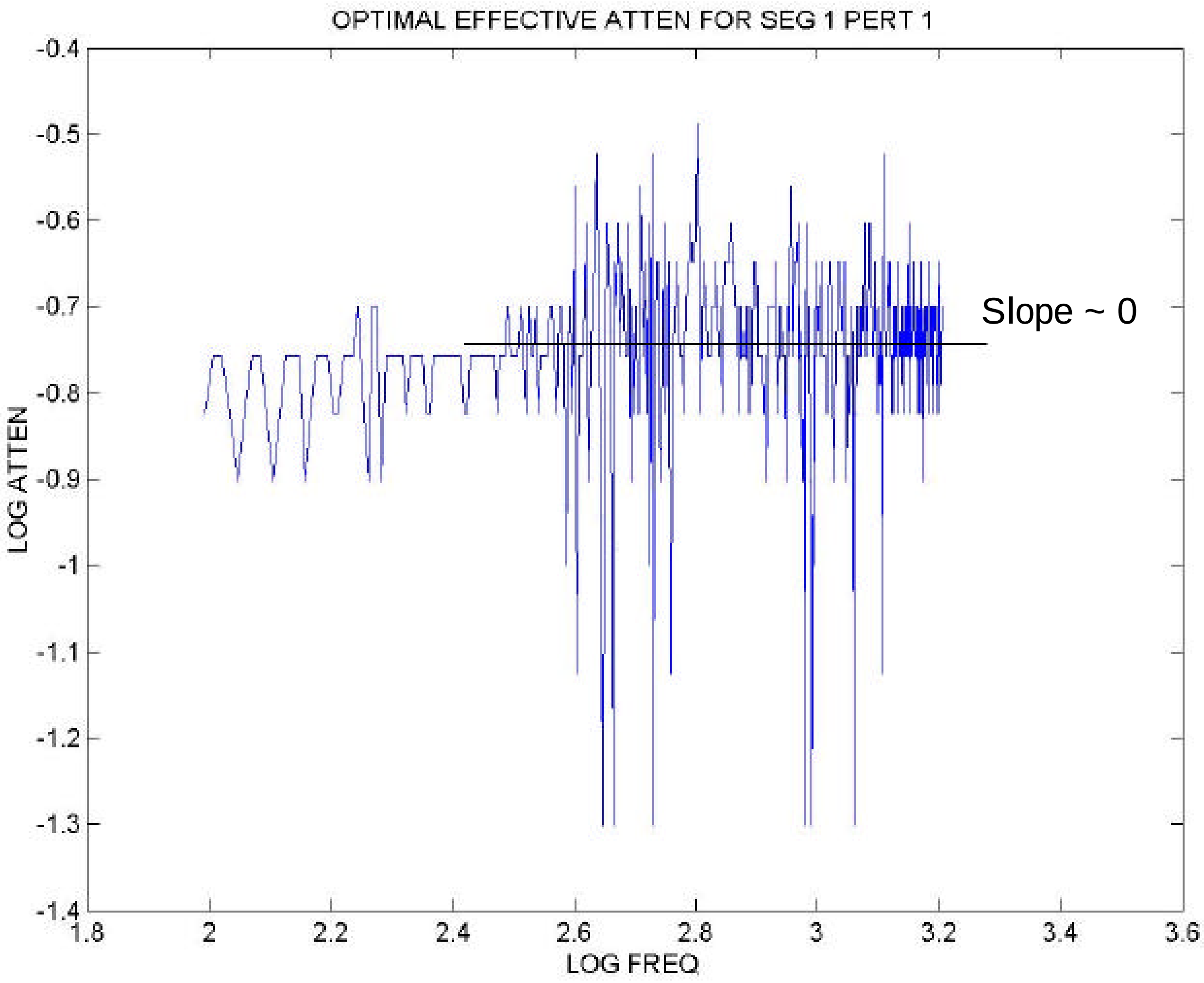
- Instead, choose simple comparison of total energy integrated over depth, i.e.

$$C(r,f,b)=\sum_j \left|p\left(r,z_j\right)\right|^2-\sum_j \left|p_b'\left(r,z_j\right)\right|^2$$

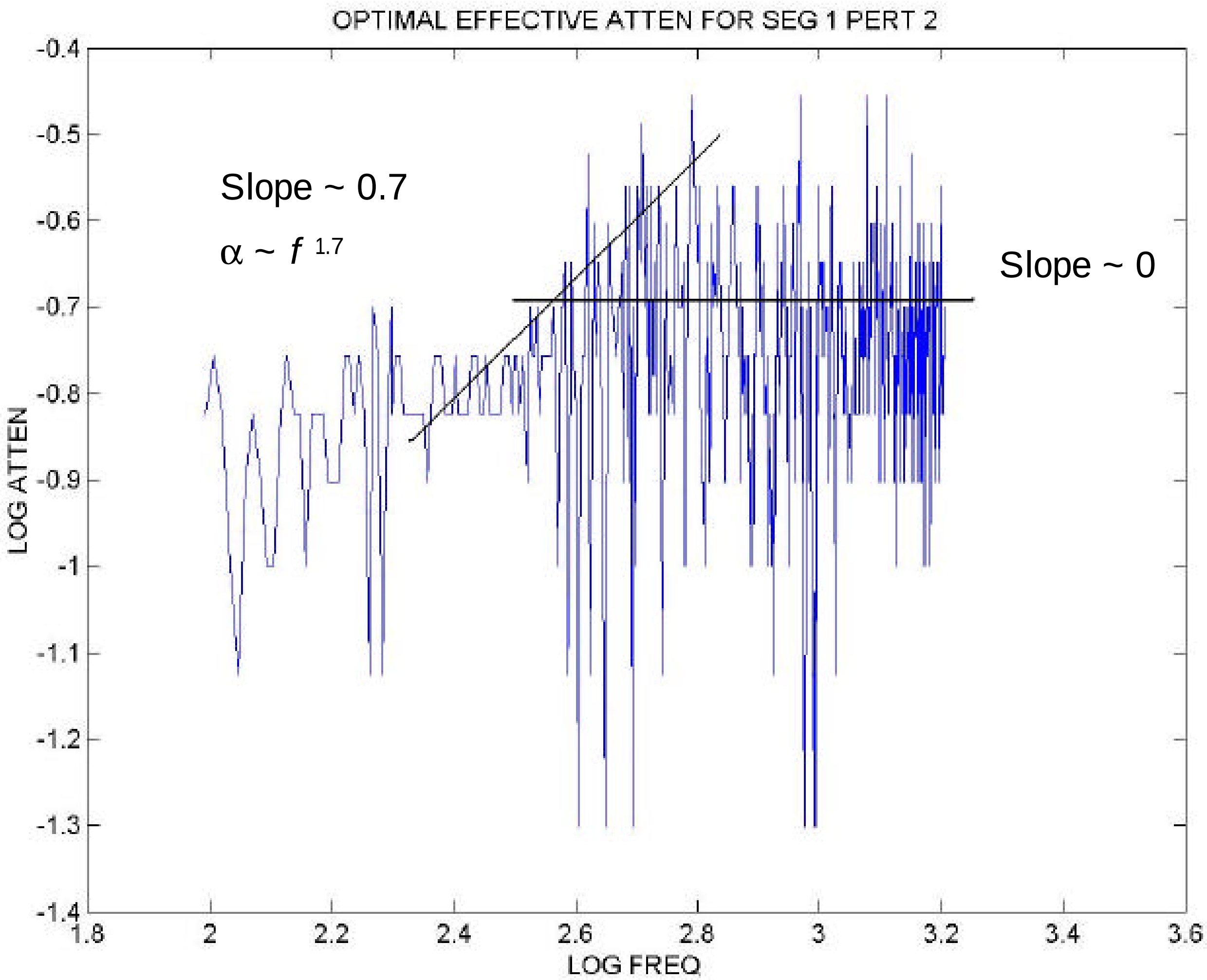
Results, Environment 1



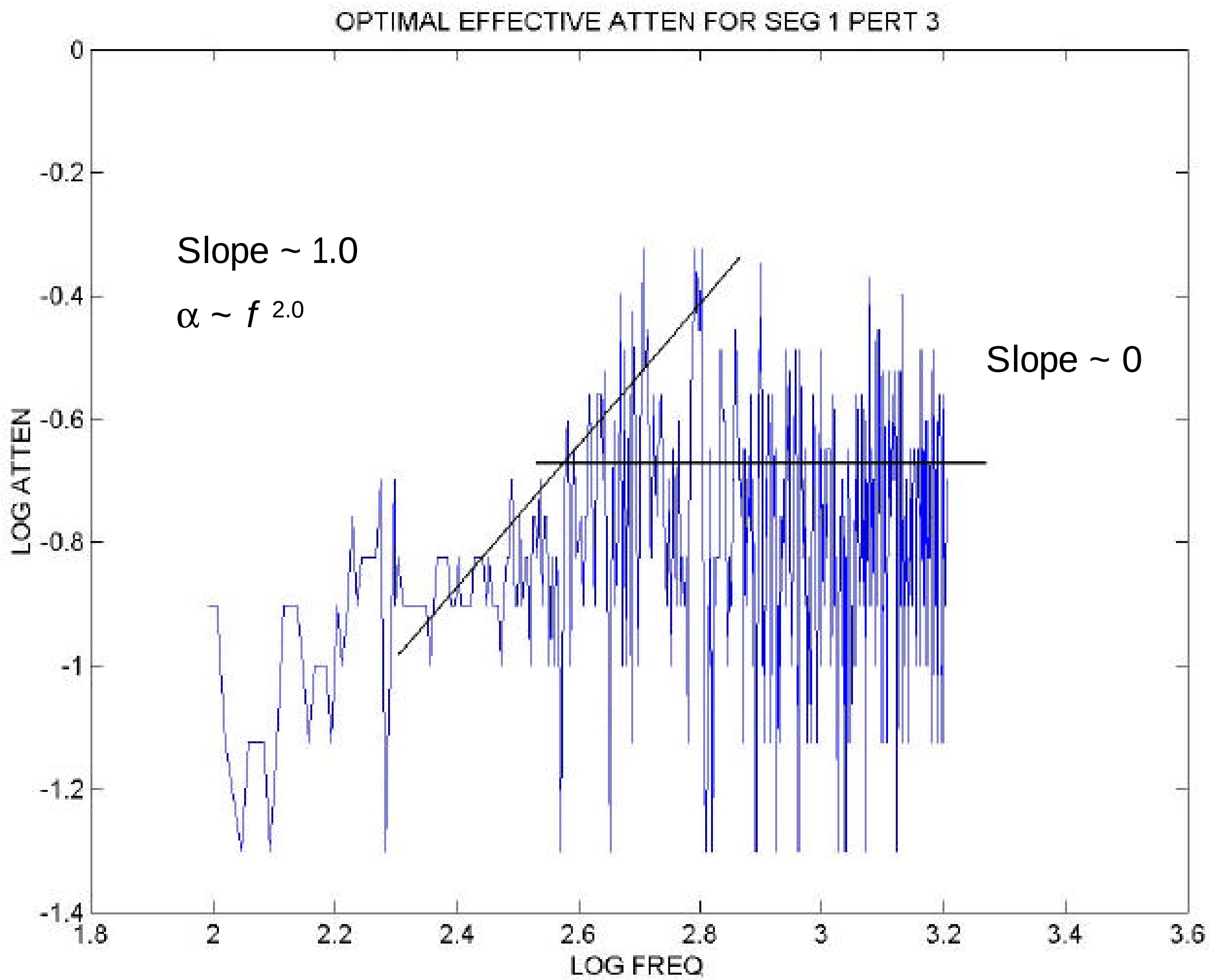
Log-log analysis of Env 1, Pert 1



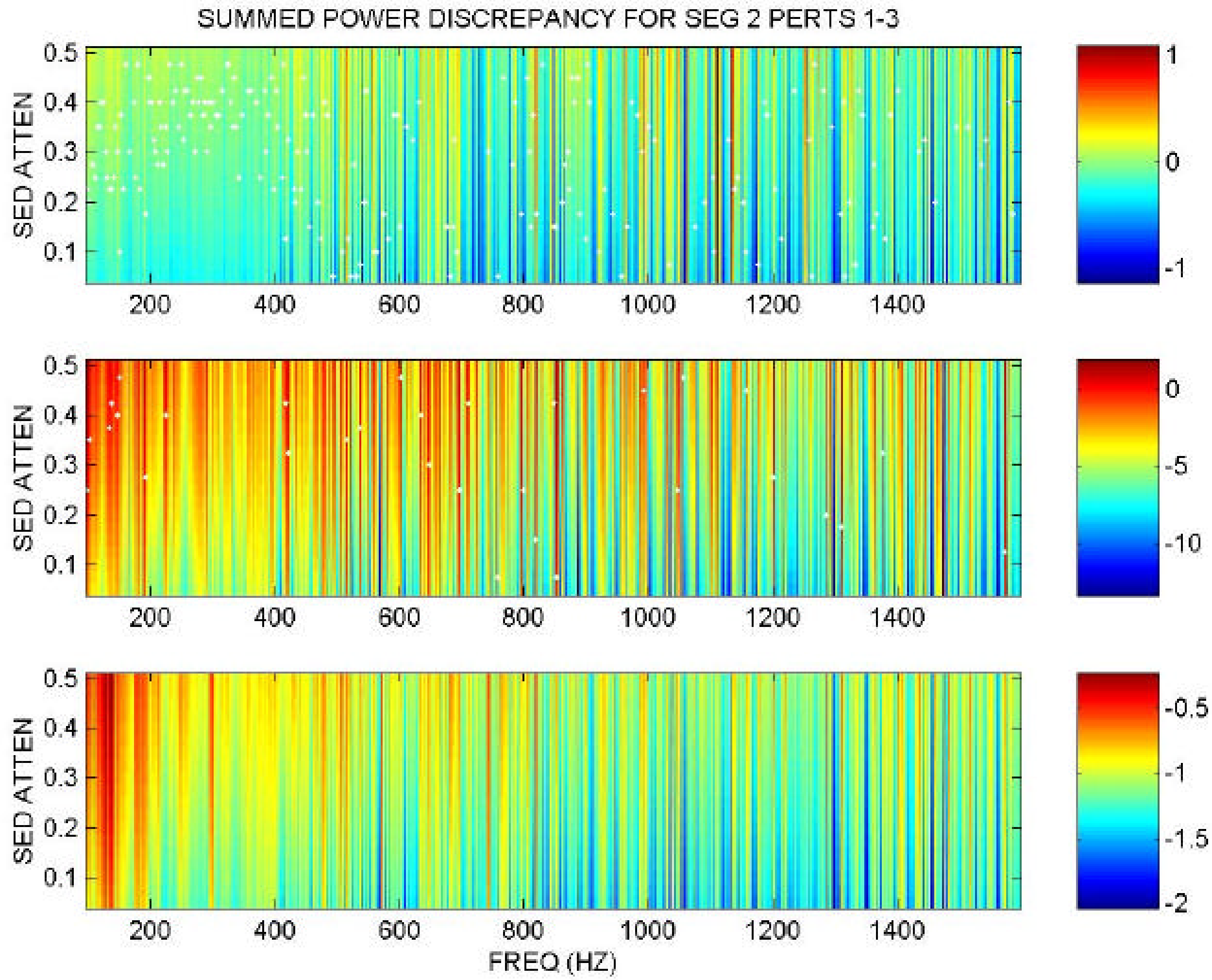
Log-log analysis of Env 1, Pert 2



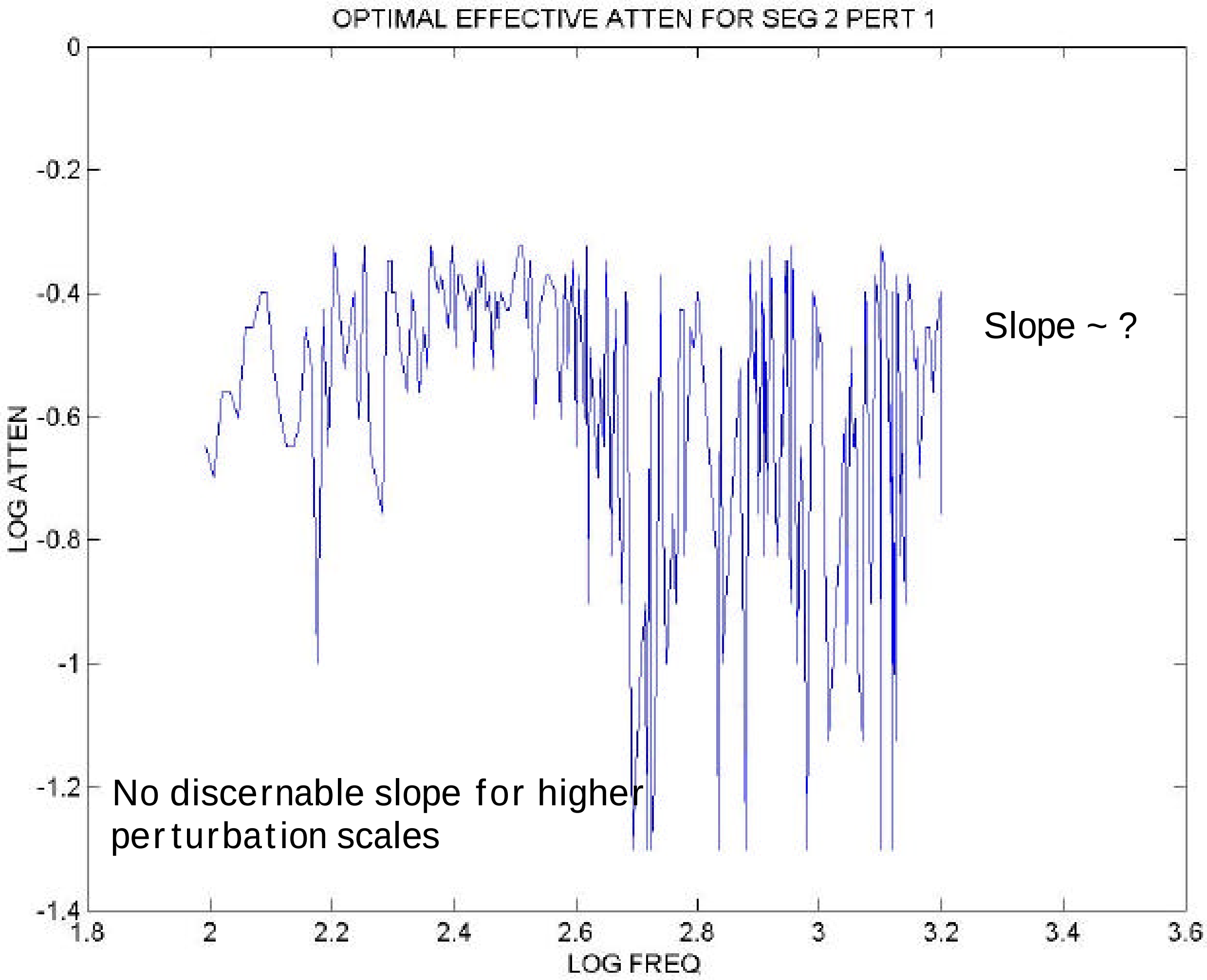
Log-log analysis of Env 1, Pert 3



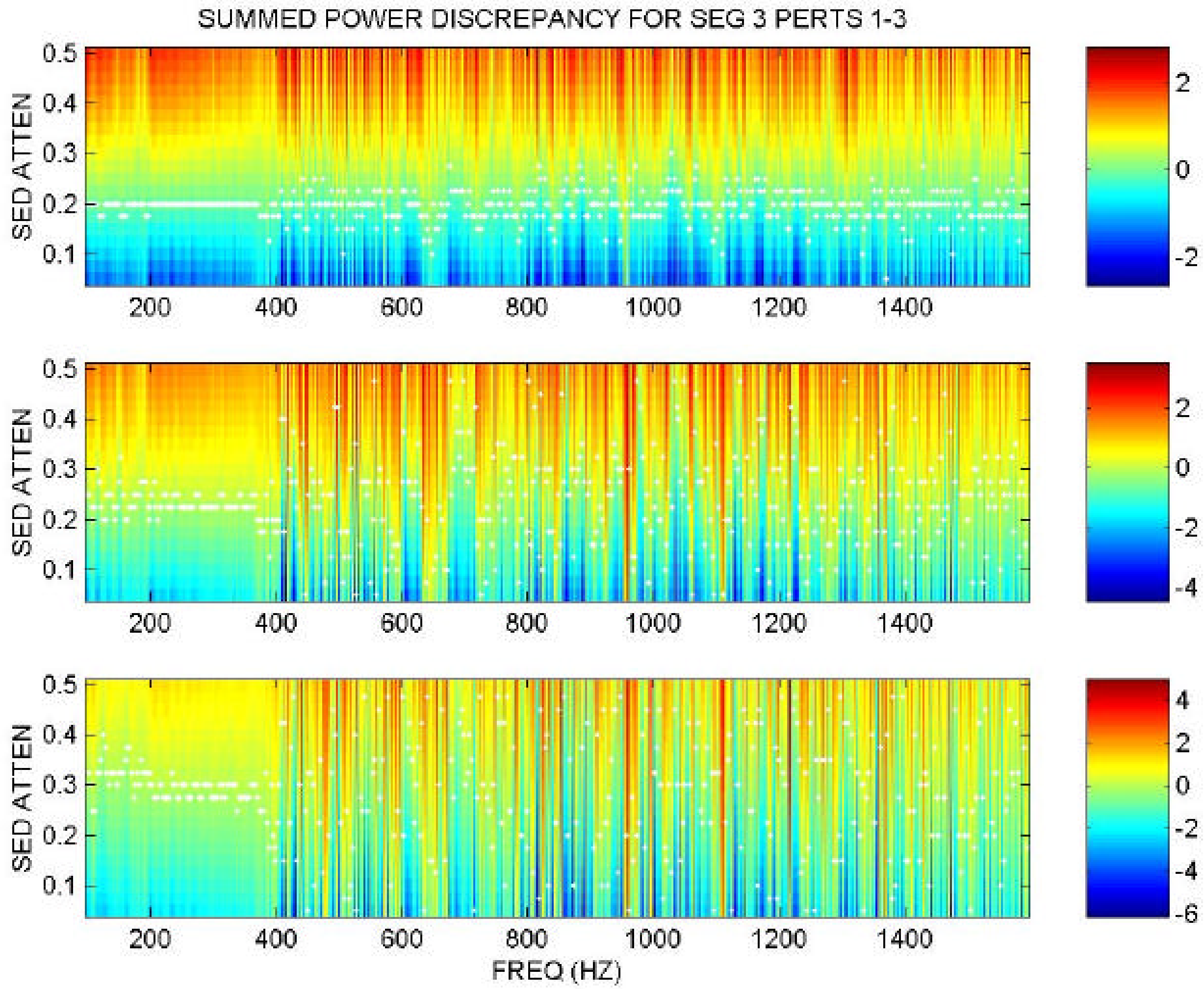
Results, Environment 2



Log-log analysis of Env 2, Pert 1



Results, Environment 3



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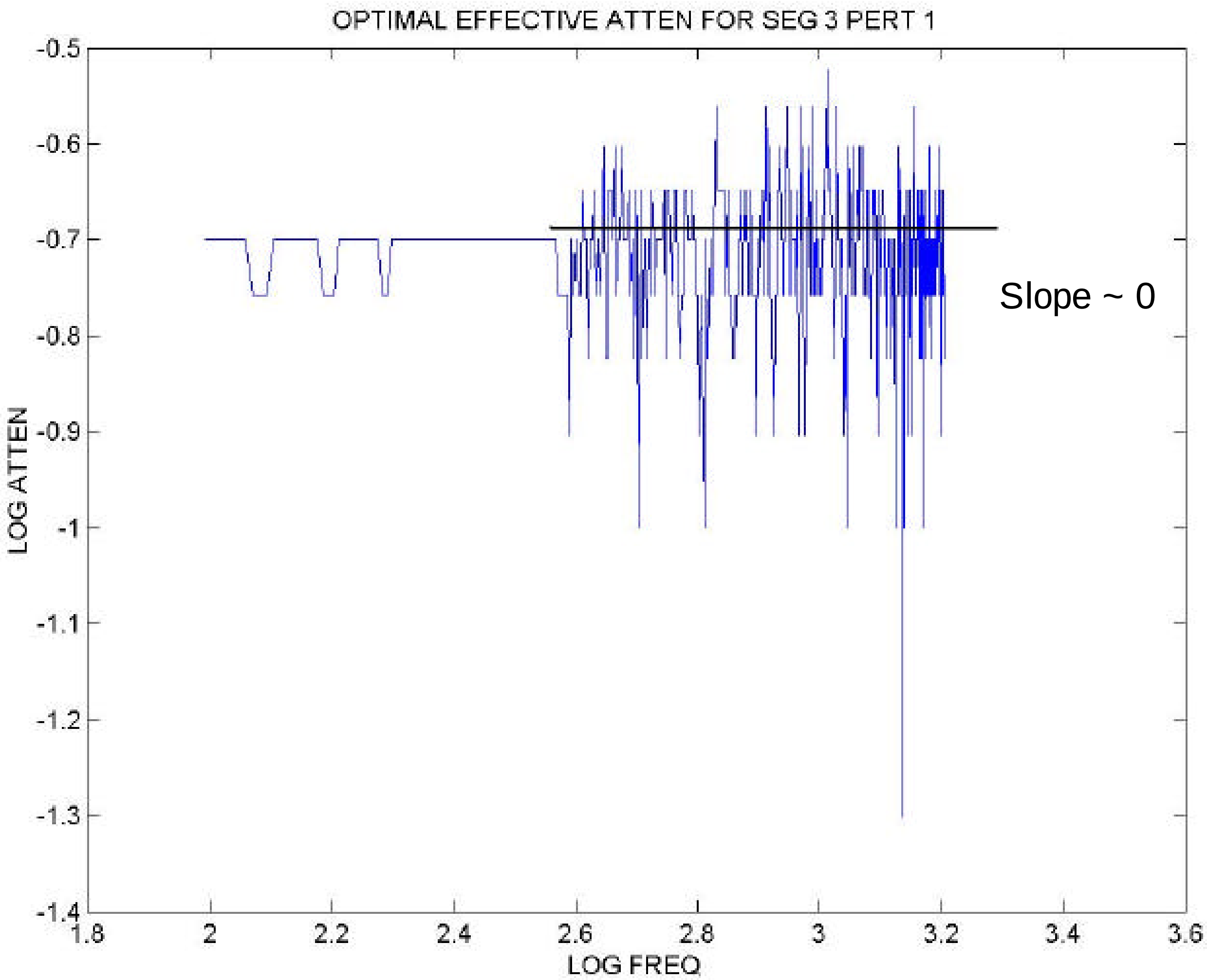

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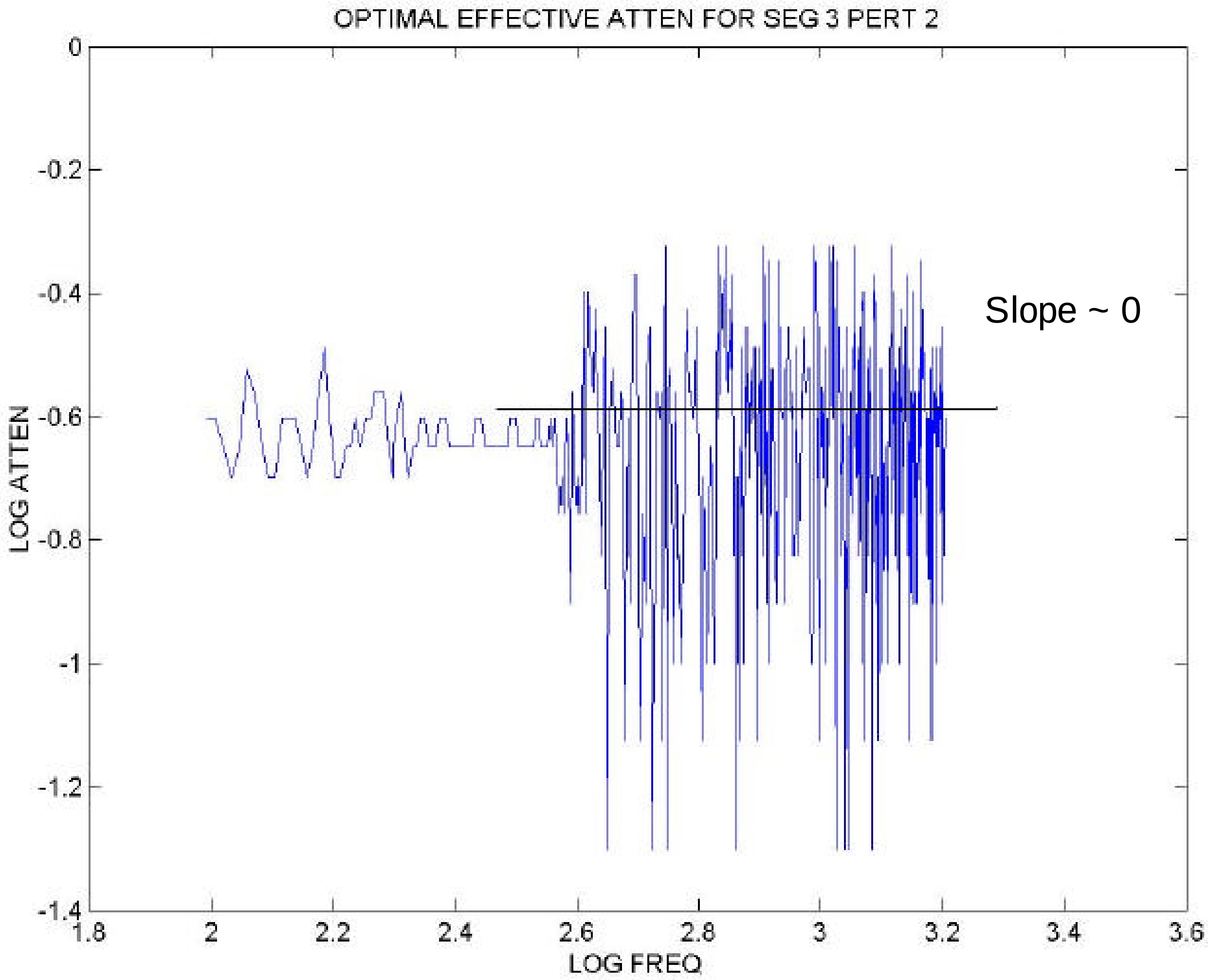

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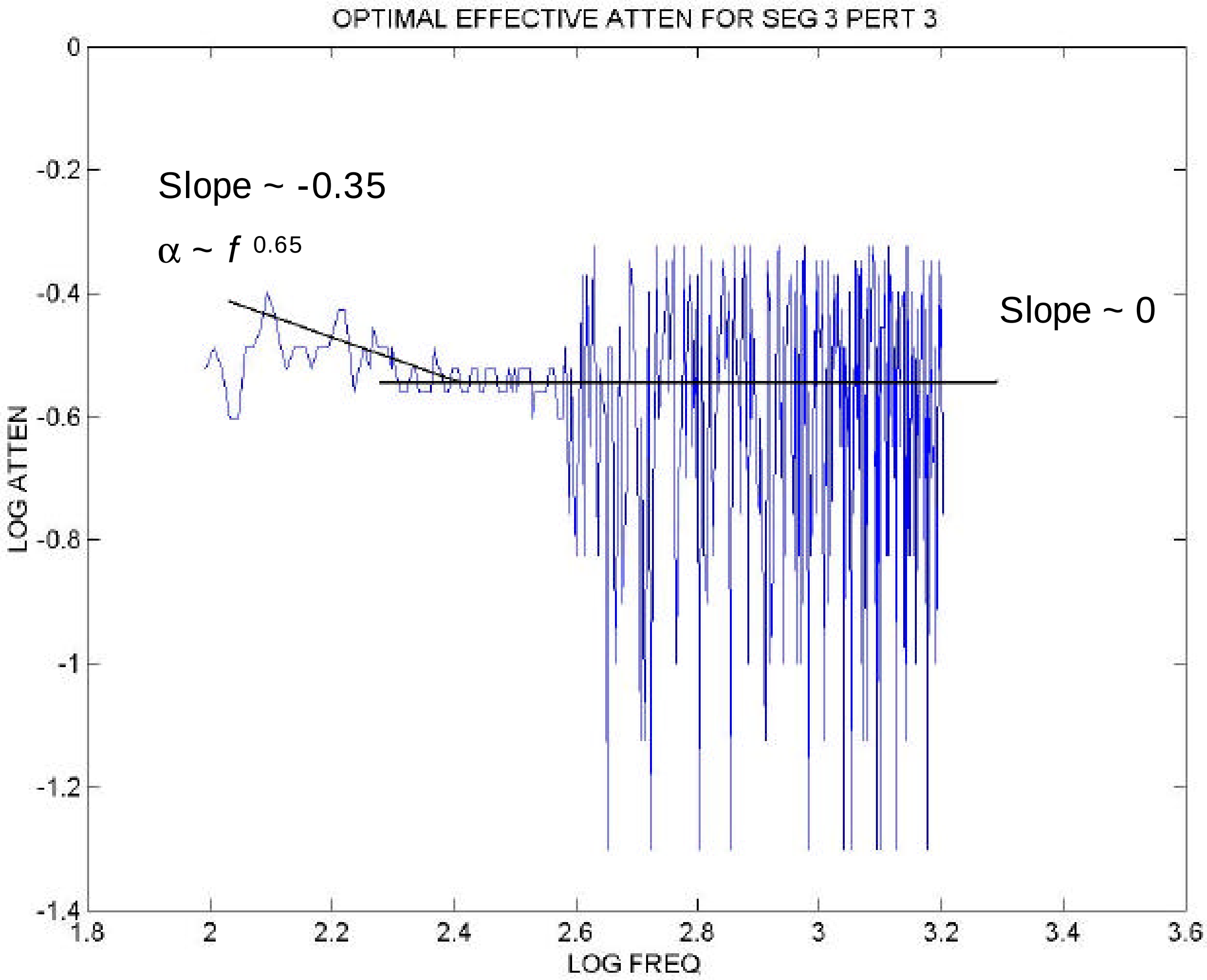
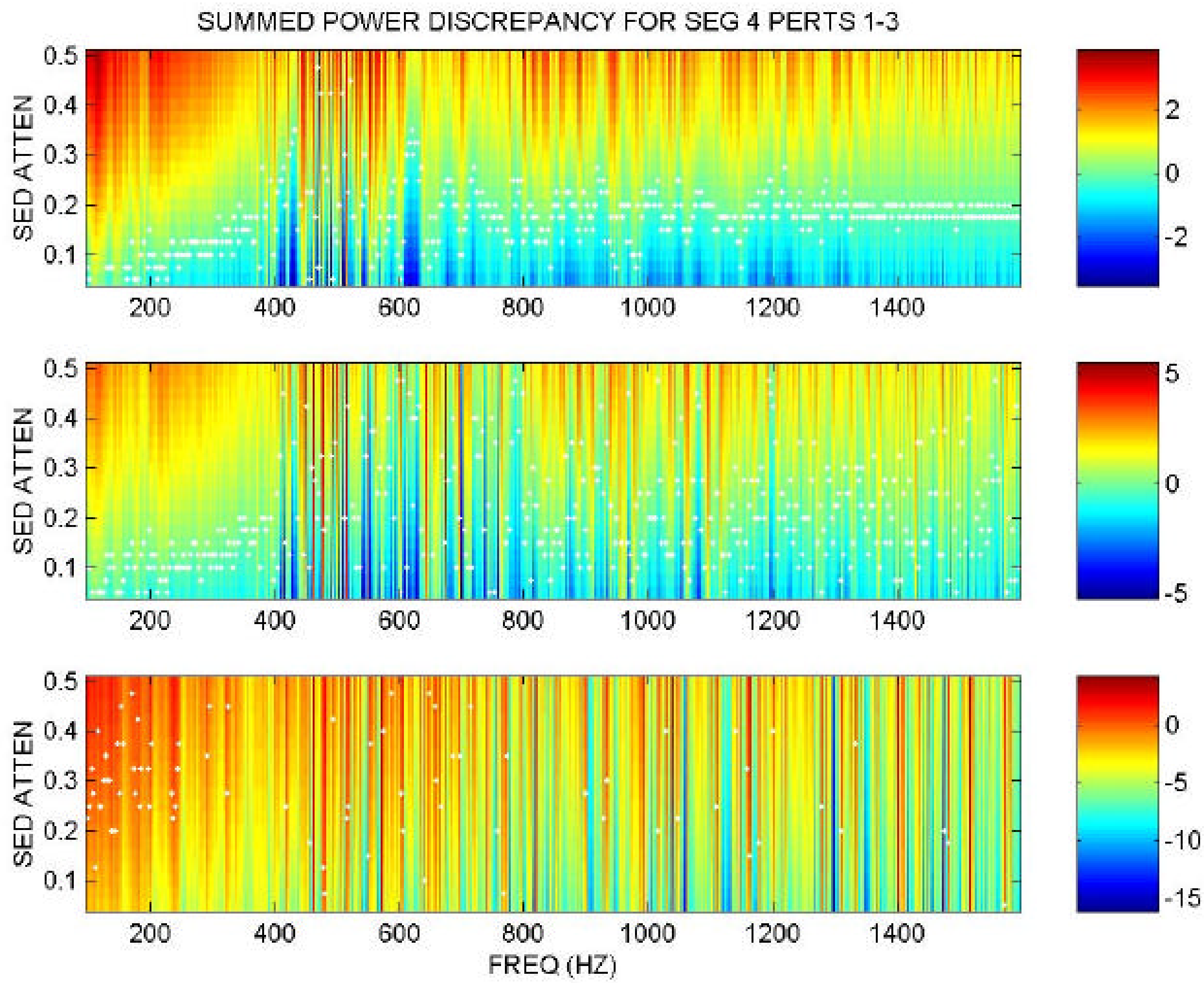
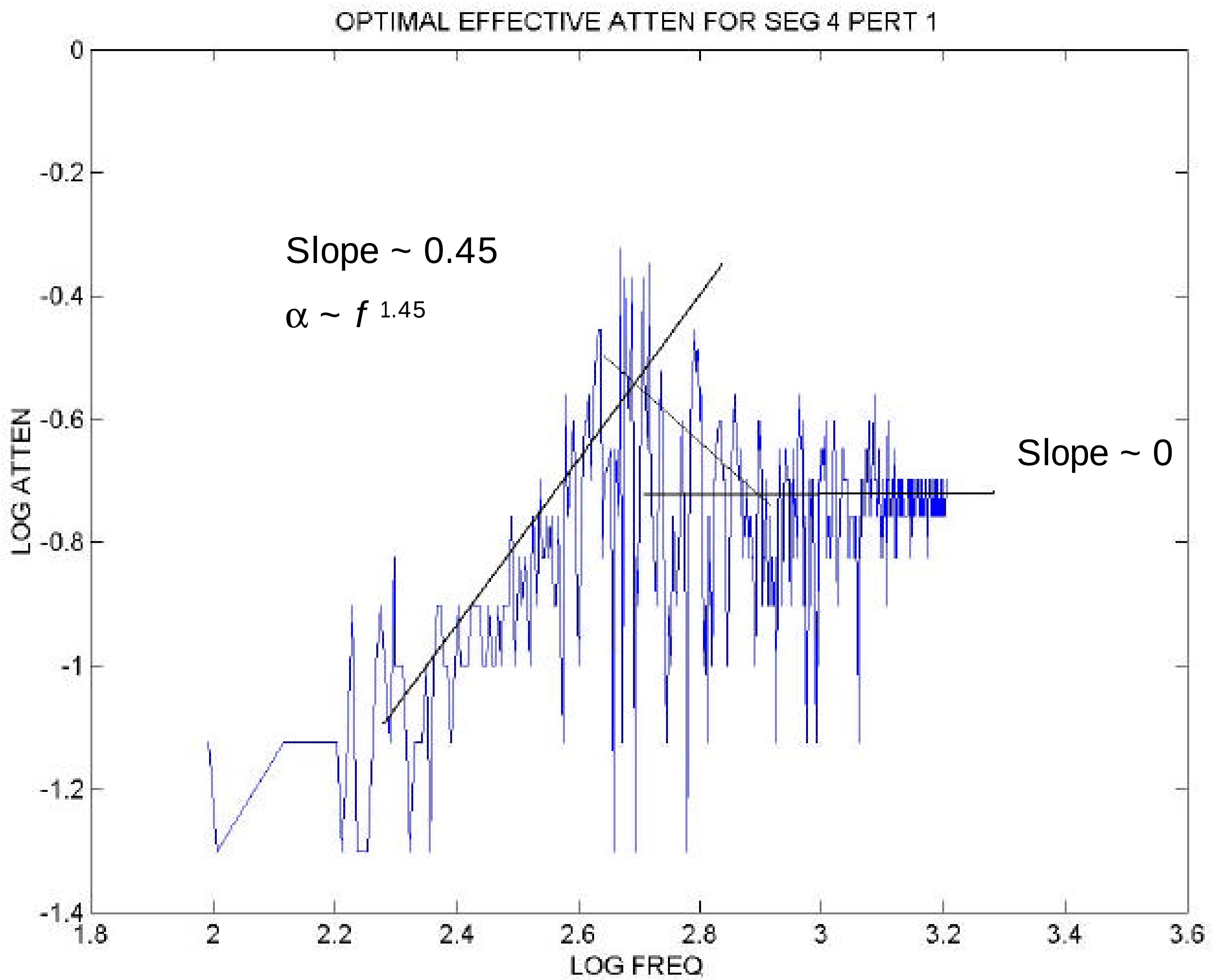


Results, Environment 4



Log-log analysis of Env 4, Pert 1



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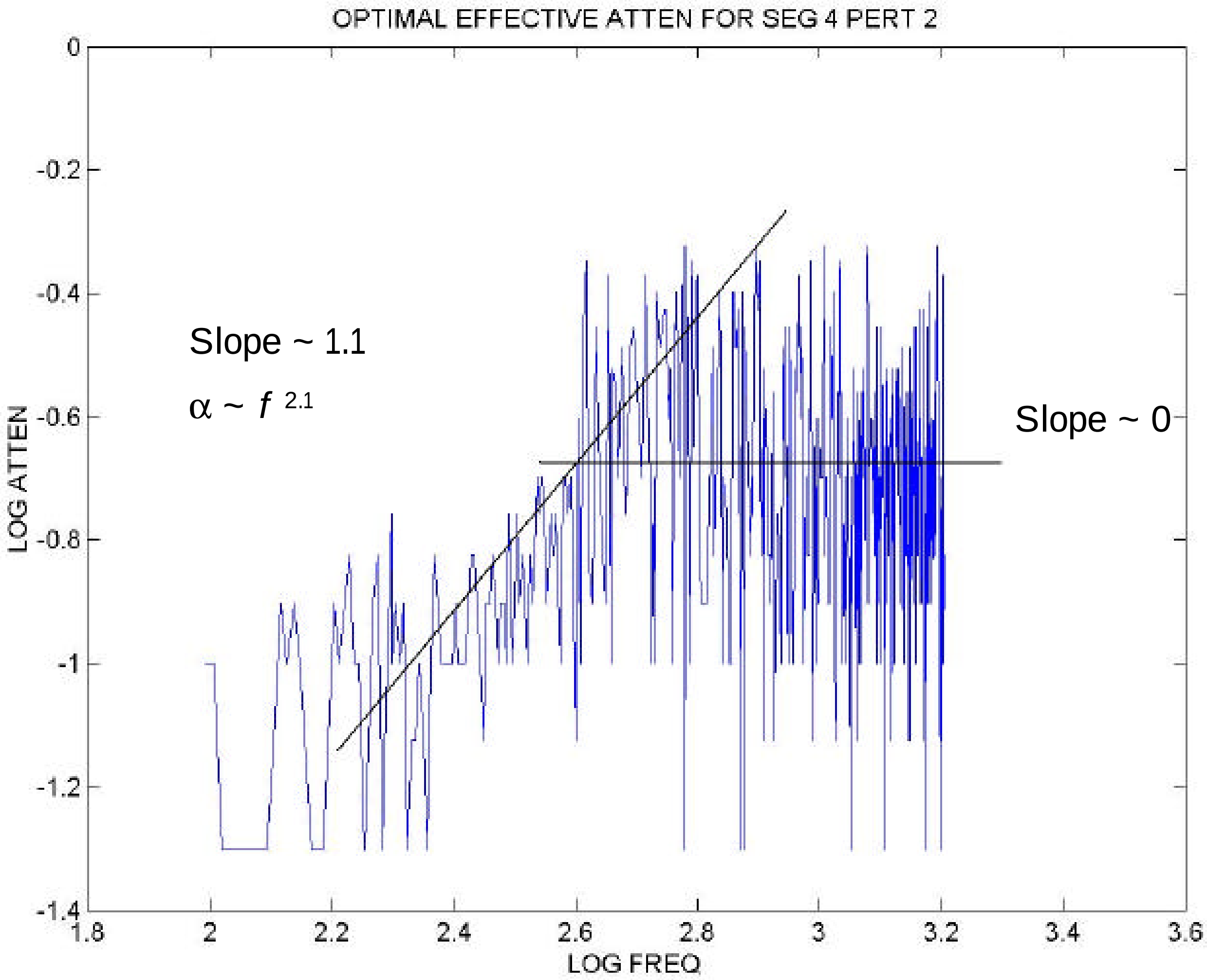
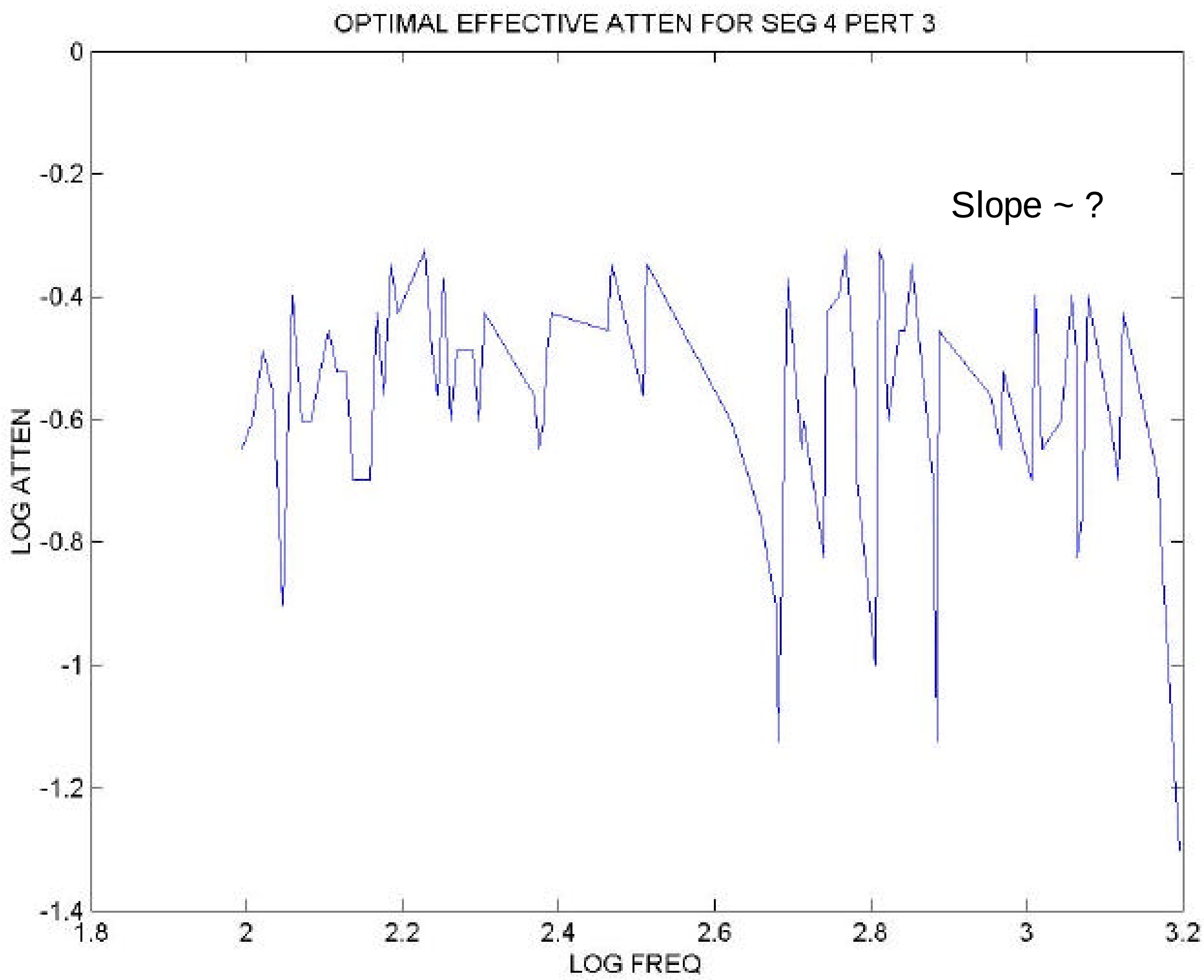


Log-log analysis of Env 4, Pert 3



Summary – Part II

- Cost function can be critical to inversion!
- Total energy in field for low (< 100 Hz) and high (> 1 kHz) frequencies do not exhibit nonlinear attenuation effect for these perturbations. Mid-frequency (100 – 1000 Hz) do exhibit nonlinear dependence for some perturbations, $\alpha \sim f^{(1.7 \rightarrow 2.0)}$.
- Gradient in sediment sound speed and basement interface roughness affect total energy the most.
- Subbottom variability still suggests reduction in power law dependence, $\alpha \sim f^{0.6}$, over low frequencies.

Summary – Part II

- Previous conjecture still valid, and may be interpreted physically as indicated below